Physical Science

INTERACTION OF MATTER AND ENERGY

HEATH / MACNAUGHTON

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Physical

Science

INTERACTION OF MATTER AND ENERGY

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Objectives of This Course

1.
To teach you to think, by allowing you to think.

2.
To give you the opportunity to learn for yourself, by doing your own investigations.

3.
To show you some of the great ideas of science that have changed the world in the past and will again in the future.

4.
To prove that science can be interesting and rewarding.

Foreword

This is a science textbook, but it will not tell you much about science. It will show you how to discover things for yourself, how to think critically and how to observe and record accurately, as scientists do. When scientists want to learn something new, they do not look for the answers to the problems they must solve in a textbook. They work them out themselves.

This book is about matter, the stuff the universe is made of. But what is matter? And where did it come from in the first place? What special quality allows some of it to be alive? And why is most of it moving? The Earth and Moon rotate and revolve, trees grow, rain falls.

In our investigations you are going to look at matter in all its different forms and, hopefully, discover some of its secrets. Many of the questions you will examine do not as yet have proper answers. It is vital that these answers be found, for only if we understand the world we live in can we build the kind of world we would like to live in.

A Note to Students on Safety in the Laboratory

Some of the investigations you will perform involve the use of chemicals and procedures that require you to take certain precautions in order to avoid accidents. Handling delicate glassware, employing corrosive and flammable chemicals and applying intense heat to liquids all involve some degree of experimental risk, which can be minimized with reasonable care. Your teacher is trained to be aware of these situations and will advise you of any precautions which must be taken. Please listen carefully to your teacher's instructions.

Introduction

0.1 The Scientific Method
0.2 Writing a Laboratory Report
0.3 The Metric System
0.4 Setting Up Data Tables
0.5 Drawing a Graph
0.6 Review
0.7 Instructional Objectives

0.1 The Scientific Method

The birth of modern science took place around the year 1600, ending a thousand years of mystery and magic and fakery. The names of those responsible – Copernicus, Galileo, Kepler, Newton – are notable because of the discoveries they made, and because of the way in which they made them – by experimentation.

The scientific method is the process of proof by experiment. The method seems simple enough. A problem arises, a hypothesis is made and an experiment is designed to test that hypothesis. The experiment begins, observations are made and a conclusion drawn. If all goes well, the problem is solved. More often, new problems arise to complicate the situation and more experiments must be done.

In the table which follows, we have summarized the scientific method and illustrated each step with an actual experiment, slightly simplified, from early in this century.

Roger Bacon, a Franciscan friar and scientist who has been credited with the modern scientific method, wrote in 1268 that scientific knowledge could only be acquired by experiment.

THE SCIENTIFIC METHOD	A CASE HISTORY
1. Decide on a problem.	What causes malaria? (People living near swamps often get malaria.)
2. Imagine some possible answers to this problem. These are called hypotheses.	(a) drinking polluted water (b) insect bites (c) eating spoiled food
3. Devise a method of attack. The hypotheses must be checked one at a time.	Let's assume that malaria is caused by mosquitoes. We'll get some volunteers and some swamp mosquitos. Some will be exposed to the insects and others not. They will all be treated in the same way.
4. Make observations.	Those bitten by the mosquitos contracted malaria. The others did not.
5. Draw a conclusion.	Swamp mosquitos can cause malaria.
6. Decide on the next problem.	(a) Do all mosquitos cause malaria? (b) Do any other insects cause malaria? (c) How does an insect bite cause malaria? (d) Can you prevent the mosquitos from causing malaria?

About 1500, Leonardo da Vinci, the famous artist/architect/engineer/scientist, wrote that science should be based on observation, and that no theory should be accepted without a crucial experiment to test its conclusions.

Of course, in this case, the experiment was a success. The hypothesis was suggested by a British doctor in Hong Kong, Patrick Manson. The investigation was carried out in India by a British doctor, Ronald Ross, in the 1890's. Dr. Ross received the Nobel prize in 1902 for determining that mosquitos pick up a parasite when they suck the blood of infected persons and pass it on to uninfected persons by biting them. It is, of course, this parasite which causes malaria.

Our problems in this book are examples of some of the most basic problems of nature. We have tried to guide you along the correct path by eliminating some hypotheses that have already been tried and found wrong. Nevertheless, you will make your own observations and draw your own conclusions from the experiments. Perhaps you will invent the next theory of matter or energy, who knows?

0.2 Writing a Laboratory Report

The laboratory reports of scientists are called "papers" and are published for other scientists to read in "journals". For example, astonomers in Canada publish their papers in the *Journal of the Royal Astronomical Society of Canada.*

There are three reasons for writing laboratory reports:

1. to record the results of investigations for reference while doing future investigations;
2. to help you to recall the results of investigations as you study for tests and examinations;
3. to report your results to other students and to the teacher.

To show you what might be expected by your teacher, we have included a sample laboratory report of an imaginary investigation.

Notice first that the report is neatly written, with headings underlined. Your report can be written on squared paper instead of lined paper. Squared paper is useful for drawing charts and graphs quickly and neatly.

The problem is stated at the top of the page, copied from the textbook.

The procedure can usually be omitted, since it is all in the text.

The observations are organized neatly – each is numbered, and is a complete sentence. All your observations must be in the report, since they are your work, and are not copied from the book.

The answers to the questions are in complete sentences, so they can be understood without reading the questions from the textbook.

The conclusion is the answer to the question asked above in the problem. Do not worry if your conclusion is different from the conclusions of others, the important thing is that it is based on your own observations.

Gordon Weber

Investigation 1.4

Problem: What happens to sugar crystals when they dissolve?

Observations:
1. The corners of the cube dissolved first.
2. The cube fell apart and pieces of it dropped to the bottom of the beaker.
3. The small pieces gradually shrank.
4. The water had streams of something flowing in it.
5. When the water was stirred, the rest of the sugar dissolved.
6. The beaker of water looked just like a beaker of water.

Questions:
1. The sugar is no longer there because the sugar just dissolved and disappeared.
2. There was something in the water as the cube dissolved, but it just looked like water.
3. You could taste the water, but this is not allowed in school, and you could see if the sugar was there.

Conclusion: The sugar is there, but I am not sure I can prove it.

0.3 The Metric System

The metric system originated in France in 1791, and has since been adopted for use in most countries. Canada is now in the midst of changing to the metric system.

In 1791, the metre was supposed to be one ten-millionth of the distance from the North Pole to the equator on a line passing through Paris. This turned out to be a rather difficult measurement to make accurately.

The metric system gives us units for every kind of quantity which can be measured, including:

length
time
area
volume
mass
force
energy
power

After 1850, the metre was defined as the distance between two marks on a specially made, carefully guarded metal bar. These days, the metre is defined as an extremely large number of wavelengths of a special kind of light, and the metal bar is obsolete.

The measurement of length is a good place to start. The basic unit of length is called a metre (m). Many objects are approximately 1 m:

the length of one walking step
the width of a doorway
the width of a sidewalk
the height of a fire hydrant

Your father, if he is quite tall, might be almost 2 m tall. Notice that the symbol for metre is just m without a period after it.

In 1960, a modernized metric system was introduced. Known as SI (Système International d'Unités), it is intended to replace all systems of measurement throughout the world. SI is used throughout this text.

Correct	Incorrect
2 m	2 m.
	2 ms
	2 ms.
	2 mtrs.
	2 M
	2 Ms.

metre comes from *metrum*, the Latin word for measure.
kilo comes from *chilioi*, the Greek word for thousand.
centi comes from *centum*, the Latin word for hundred.
milli comes from *mille*, the Latin word for thousand.

This symbol is always written exactly the same, everywhere in the world.

Other units of length are obtained by adding a prefix to the base unit. A prefix is a syllable added before a word. These same prefixes may be used with all metric units, not only with the metre.

PREFIX	MEANING	SYMBOL
kilo	makes a unit 1000 times greater	k
centi	makes a unit 1/100 as great	c
milli	makes a unit 1/1000 as great	m

tera (t)	10^{12}
giga (G)	10^{9}
mega (M)	10^{6}
kilo (k)	10^{3}
hecto (h)	10^{2}
deca (da)	10
deci (d)	10^{-1}
centi (c)	10^{-2}
milli (m)	10^{-3}
micro (μ)	10^{-6}
nano (n)	10^{-9}
pico (p)	10^{-12}
femto (f)	10^{-15}
atto (a)	10^{-18}

Using these three prefixes, we make three new units of length:

kilometre	km
centimetre	cm
millimetre	mm

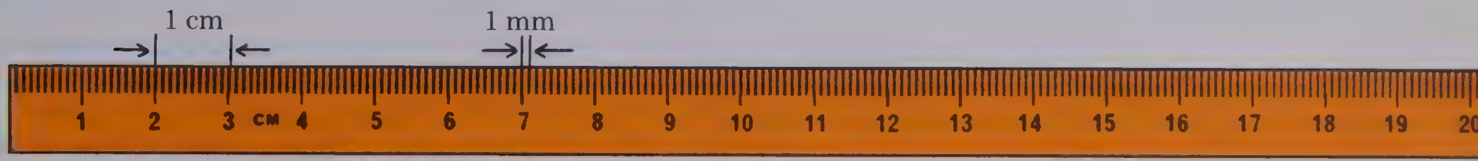
Distances of about 1 km would include:

several city blocks
1000 large walking steps

the length of ten football fields, end to end

Distances of about 1 cm are:
- the width of a baby finger
- the radius of a nickel (a nickel is almost exactly 2 cm across)
- the width of a ball-point pen top
- 10 mm (of course)

Distances of about 1 mm are:
- the width of a pencil lead
- the width of the tip of a ball-point pen

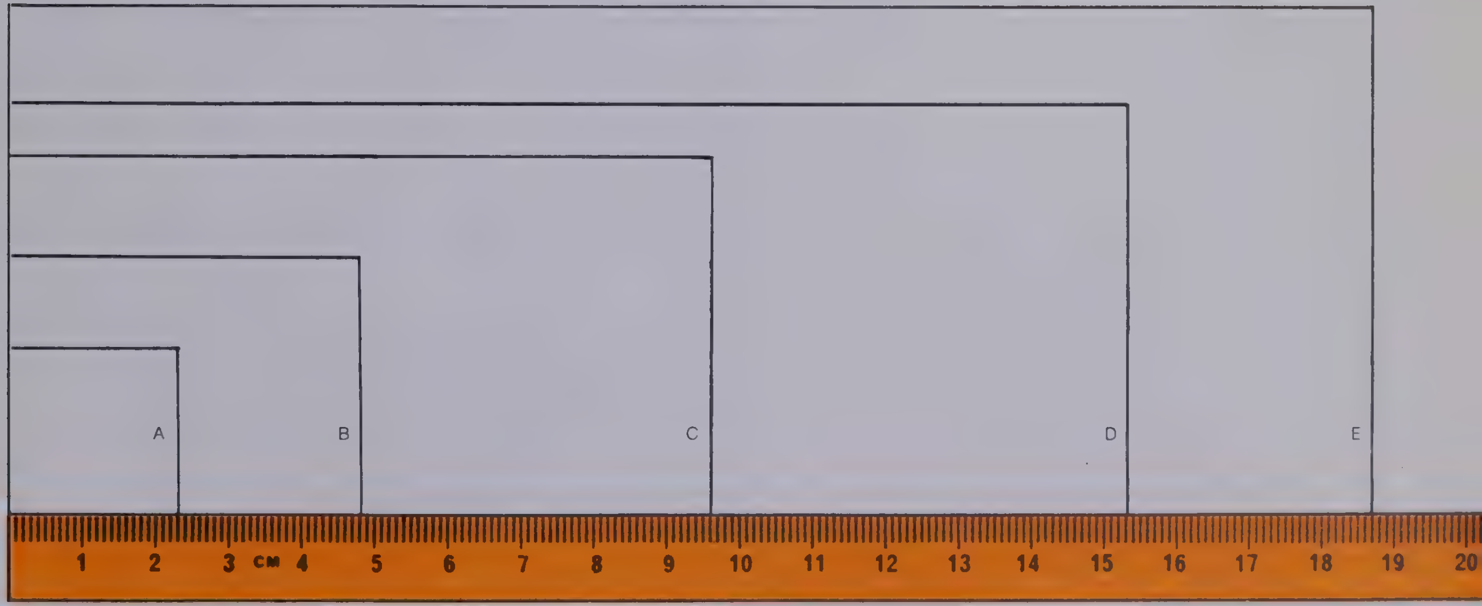


The conversion from one length unit to another is simple if you remember that:

1 cm = 10 mm
1 m = 100 cm
= 1000 mm
1 km = 1000 m

I don't think anyone will ever ask you how many millimetres there are in a kilometre, but, just in case, there are one million.

You can practice measuring lengths using the diagram below. Measure the length of each rectangle in centimetres and in millimetres. The length of rectangle A is 2.3 cm, not 2 cm and 3 mm. It is, of course, also 23 mm.



ANSWERS:

rectangle	cm	mm
A	2.3	23
B	4.8	48
C	9.6	96
D	15.3	153
E	18.7	187

You may have noticed that the last two measurements are not exact. They have been rounded off to the nearest 0.1 cm or mm. A scale with finer divisions can give you a more exact answer, but *never* the *exact* length of the object. This is one of the problems which scientists have to live with: there are no absolutely accurate measurements.

This next project is fun to do and good practice for learning metric units of length. You need a metre stick or, better, a cloth or metal tape measure marked in centimetres. The idea is to measure each of the following distances, eventually. First, you and your partner each estimate the length in centimetres. Then measure, and see whose estimate is the most accurate.

1. length of your thumb
2. length of pen or pencil
3. height of this page of the text
4. length of arm from elbow to fingertips
5. length of nose from bridge to tip
6. your height
7. width of cover of this book
8. height of desk
9. distance between pupils of your eyes
10. length of shoe
11. distance around wrist
12. length of chalkboard eraser
13. length of metre stick
14. width of window pane
15. width of doorway
16. distance around waist
17. length of a hair from your head
18. width of one handspan
19. length of the room
20. width of your knee

0.4 Setting Up Data Tables

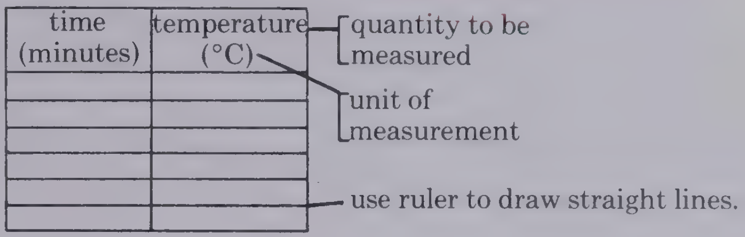
The measurements from experiments must be organized so they may be understood, in order to arrive at the best conclusion.

Data tables help you to do this. As you read the procedure of an investigation you should look for headings for the data table.

For example, if the procedure says, "As you heat the beaker of water, measure its temperature every minute", then you should make up a data table with the following headings:

The data table should be drawn up and ready to use as you do the investigation. To avoid errors, don't record your data on scraps of paper to copy out later.

The left-hand column usually contains the data which you, as the investigator, have control over. In this case, it would be "time", since you will take a temperature measurement every minute.



time (minutes)	temperature (°C)

The table can be quite complex. It is not easy to include all the necessary headings the first time.

PROCEDURE:

Fill a beaker with warm water. Find the mass of the beaker, a sugar cube and a stirring rod. Put the sugar cube in the water and stir until it dissolves. Find the total mass of the beaker and the stirring rod. Was there any change?

The data table for this investigation needs three headings. Do you see what they must be?

total mass before dissolving (g)	total mass after dissolving (g)	change in mass during dissolving (g)

Data tables should be clearly labelled, and should be included in the Observations section of your laboratory report.

0.5 Drawing a Graph

The observations of an investigation are often pairs of numbers. These are recorded in a table, such as the following:

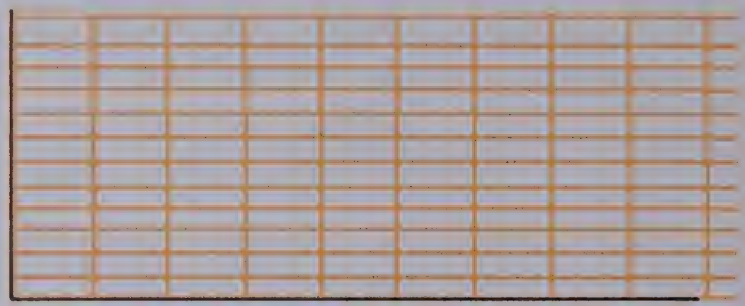
length (cm)	volume (cm^3)
1.1	6.6
2.3	13.8
7.3	43.8
9.5	57.0
4.2	25.2
6.5	39.0

pairs of numbers representing data from an investigation

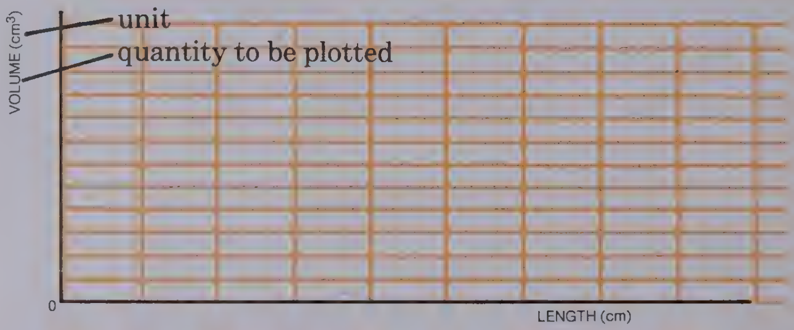
In most experiments, one of the measurements in the data table is under the control of the experimenter. It is called the "independent variable" and should be plotted along the horizontal axis. The other measurement, called the "dependent variable", is plotted vertically.

Can you see any pattern in the data? Is there a relationship between the pairs of numbers? A graph should reveal this relationship.

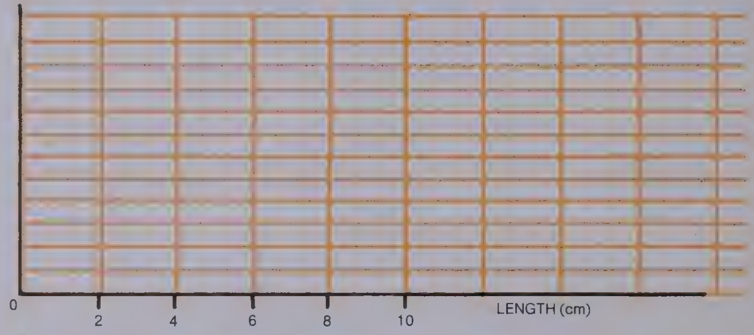
On a sheet of graph paper, draw two number lines, or axes, at right angles to each other. Make the graph as large as possible on the paper.



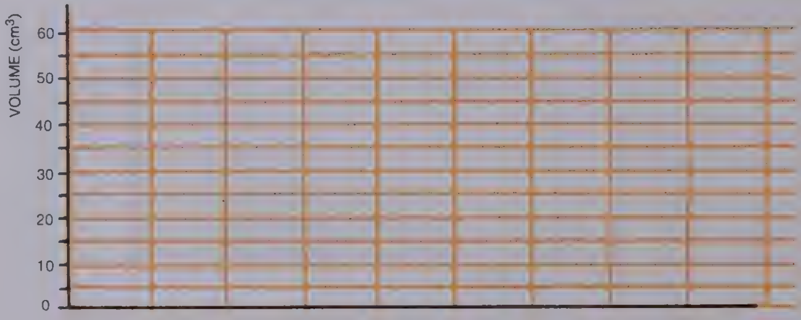
For most of our graphs, the point where the axes cross will be zero on both axes. The quantity in the left-hand column of your data table is usually plotted along the horizontal axis (in this case, "length"). The other is plotted vertically.

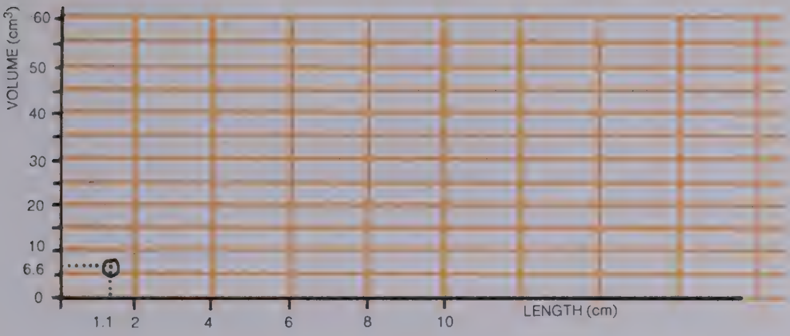


Look at the length numbers. The largest is 9.5. Label this axis from 0 to 10, spreading the numbers out evenly along the axis. It is not necessary to number each line or to include every number.

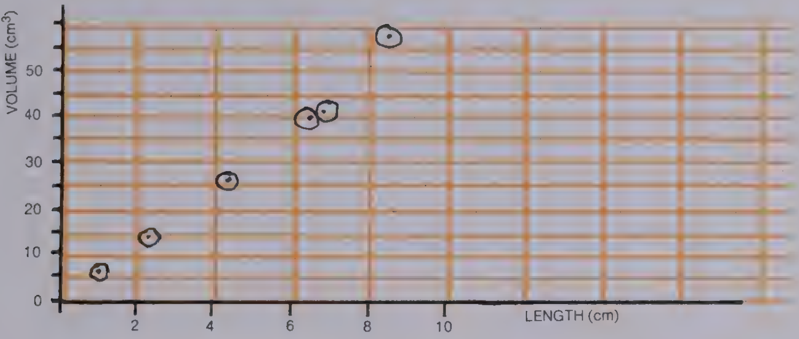


Now look at the volume numbers. They range from 6.6 to 57.0. Label this axis from 0 to 60. The numbers on this axis need not be the same distance apart as those on the other axis.

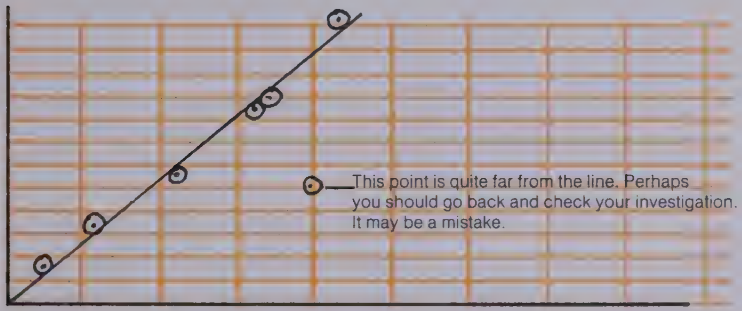




Now plot the points. For point number one, go along the length axis to 1.1 (you will have to estimate where this is), then draw a short vertical dotted line. Now go up the volume axis to 6.6 (again, you will have to estimate) and draw a short horizontal dotted line. Draw a dot at the point where these two dotted lines intersect. A small circle may be drawn around the point.

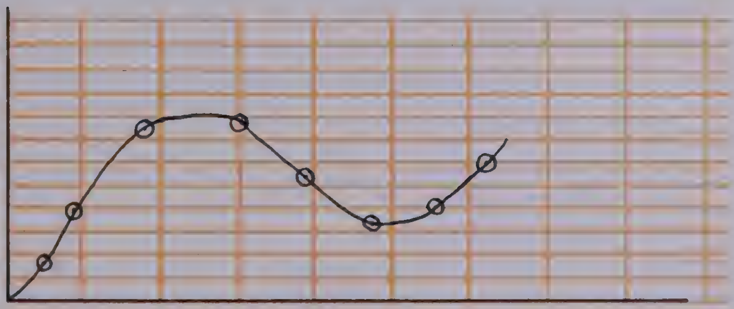


Repeat for each of the other points.


This point is quite far from the line. Perhaps you should go back and check your investigation. It may be a mistake.

If the points seem to lie on a straight line, then take your ruler and draw a straight line through them.

Sometimes the points are nearly on a straight line. In this case, we still draw a straight line, but we try to draw it as close as possible to the points.



Often the relation is not linear: the points do not lie on a straight line. Do not just join the dots. Draw a smooth curved line through the points.

0.6 Review

1. Use the table to draw a proper graph. Be sure to label the axes and circle the points. Don't forget to draw a smooth line through them, using a ruler, if needed.

length (cm)	area (cm^2)
0	0
2	8
3	12
9	72
5	40

2. A boy goes to a store to buy doughnuts every day for a week. Each day he buys a different number. The clerk charges a certain amount for each doughnut and extra for the box. Draw a graph of the data.
   (a) How much does the box cost? Use your graph to find out.
   (b) How much does one doughnut cost, without a box?
   (c) How much would six doughnuts cost? Use your graph to answer.
   (d) Will this graph tell you the cost of 120 doughnuts? Why not?

number of doughnuts	cost (cents)
3	50
5	78
8	120
4	64
7	106

Graph Checklist
1. Draw axes with ruler.
2. Make the graph as large as possible.
3. Number each axis carefully.
4. Label each axis with the quantity involved and the unit of measurement used.
5. Circle each plotted point.
6. Draw a smooth curve to represent the relation.
7. If the graph seems to be a straight line, use a ruler to draw it.

3. Often a line on a graph has an equation, which shows the relationship between the two quantities being plotted. For example, draw the graph of:

$$y = \frac{1}{2}x + 2$$

First fill in the table in your notes, then draw the graph. Can you figure out the equations for questions 1 and 2?

x	y
2	3
4	4
6	
8	
10	

4. A space scientist records the speed of the launch vehicle at various times after liftoff. His data is recorded in the following table. Draw a graph of these results with time plotted along the horizontal axis.
   (a) What is the speed of the rocket at fifteen seconds?
   (b) What is the speed of the rocket at 65 seconds?
   (c) At what time does the rocket have a speed of 2000 km/h?

time since liftoff (seconds)	speed (km/h)
0	0
10	400
20	900
30	1500
40	2200
50	3000
60	3900

0.7 Instructional Objectives

Instructional objectives are included at the end of each chapter. They describe exactly what you, the student, must be able to do after completing the chapter. Test questions will be made up using this list as a guide. If you can do everything stated here, you are certain to do well in this course.

1. To describe the steps in the scientific method and to use them in reports on classroom investigations.

2. To measure lengths using metric units and their symbols: the millimetre (mm), centimetre (cm), metre (m) and kilometre (km).

3. To estimate the lengths of common objects, in metric units, to within 20% of the actual value.

4. To change from one metric unit to another, by multiplying or dividing by the correct power of ten.

5. To read and analyze an investigation, and to set up a data table to record the results of the investigation.

6. To plot points on a graph, with properly labelled axes, and to draw a smooth curve through the plotted points, given information from a data table.

7. To extract further information from a graph, by interpolation or by extrapolation: that is, by reading points on the curve as plotted, or on the curve as extended.

Dissolving

1.1 Pure Substance or Mixture?
1.2 Making Solutions
1.3 Measuring Volume
1.4 Writing a Laboratory Report
1.5 Investigation: Dissolving Sugar Crystals
1.6 Can You Trust Your Senses?
1.7 Making Accurate Observations
1.8 Weight and Mass
1.9 Investigation: Mass / Dissolving
1.10 Investigation: Other Solutions
1.11 Saturated and Unsaturated Solutions
1.12 Heat and Temperature
1.13 Investigation: Temperature / Solutions
1.14 Investigation: Solutions / Heat
1.15 The Metric System
1.16 Summary
1.17 Further Investigations
1.18 Review
1.19 Instructional Objectives
1.20 Glossary

1.1 Pure Substance or Mixture?

The stuff of which all things are made is called matter. Matter can be classified as either a pure substance or a mixture. Some examples of pure substances are sugar, water, nylon, oxygen, copper sulphate and uranium. Pure substances contain only one kind of matter.

Matter can be classified in many ways. It is pure substance or mixture. It is solid, liquid or gas. It is organic or inorganic. But just what is it?

Mixtures contain more than one kind of matter. Sometimes they are easy to identify. A tossed salad is obviously a mixture of substances of many different sizes, shapes and smells. Milk is more difficult to classify unless you look at it under a microscope. Then you will see tiny drops of butterfat suspended in water. Two substances make it a mixture.

A solution is a special kind of mixture. When salt dissolves in water, it seems to disappear altogether. Even under the microscope, there are no signs of anything except the water and a few dust specks. If the salt is still there, how could it mix so thoroughly with the water? And if it mixes so well, how do we decide that it is a mixture and not a pure substance?

1.2 Making Solutions

The simplest solutions are made by dissolving a solid, such as sugar (the solute), in a liquid, such as water (the solvent). Solutions can be made using other states of matter besides liquids. Oxygen, a gas, dissolved in water, keeps fish and other marine life alive. The atmosphere is itself a solution of gases in gases, mainly oxygen and nitrogen, with some carbon dioxide and small amounts of other rare gases thrown in.

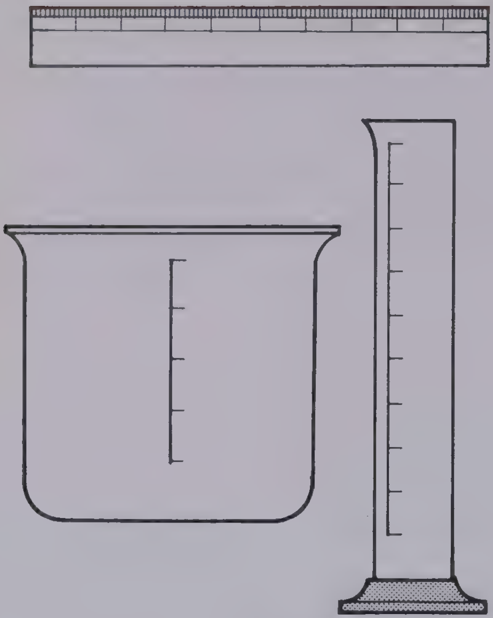
The atmosphere consists of

nitrogen	78.03%
oxygen	20.99%
argon	0.94%
carbon dioxide	0.03%
hydrogen	0.01%
neon	0.0012%
helium	0.0004%
birds	0.0001%

Molten copper mixed with molten zinc produces a solution which, when it hardens, is called brass. Ethylene glycol and water are mixed to form a solution of a liquid in a liquid, commonly used as antifreeze in car radiators.

The amount of solution and the amount of each dissolved material can be quite important. One way to measure amounts of matter is by volume. If you wish to review the units of volume in the metric system, you should do the following investigation before making your first solution.

If you have never used the metric system, or if you want to have a more complete review, look in the back of this book in the Appendix before going on.



1.3 Measuring Volume

Matter takes up space. The space in a milk carton can be filled with milk. The space in your gas tank had better be filled with gasoline.

In the metric system, the standard amount of space is contained in a cube 10 cm wide, 10 cm high, and 10 cm deep. It is called a litre (ℓ).

If you have never seen one, you should make yourself a cardboard litre cube. This will help you when you have to buy things like milk, orange juice, gasoline, liquid detergent or shampoo in litres.

In the laboratory, a smaller unit is often more useful. It is the space inside a small cube measuring 1 cm along each side. It is called a millilitre (ml). How many millilitres are there in a litre? Can you calculate it mathematically?

The volume of any rectangular object can easily be found. Multiply its length by its width, then multiply that result by its height. If you are using a centimetre scale, the answer will be in cubic centimetres (cm^3).

The volume of a litre is:

$10\ cm \times 10\ cm \times 10\ cm = 1000\ cm^3$

The volume of a millilitre is:

$1\ cm \times 1\ cm \times 1\ cm = 1\ cm^3$

Therefore, there must be 1000 ml in every litre.

In fact, whenever you see a "milli" on the front of a unit, it indicates a new unit just 1/1000 as big as the basic unit.

My car holds 74 ℓ of gas and gets about 15 ℓ/100 km. How far can it go on one full tank?

MATERIALS:

100 ml graduated cylinder
empty milk carton
sponge
rubber stopper, or small mass or piece of chalk

PROCEDURE:

Using the 100 ml graduated cylinder, fill the milk carton with water. Measure the length, width and height of the milk carton in centimetres and calculate its volume in cubic centimetres. Change this answer to millilitres and to litres. Did you get the same answer as before? Why? Measure the volume of one of the small objects listed above, using a graduated cylinder partly filled with water. Could you find the volume of a sponge in the same way? Does the volume of a sponge include the holes? Test your measuring skill by measuring out the following amounts of water, one by one, into a 250 ml beaker: 25 ml; 30 ml; 17 ml; 28 ml. Pour all of the water back into the graduated cylinder and measure its total volume. Now calculate what this volume should be.

A quart of milk is just a little larger than a litre of milk; 500 g of butter is just a little larger than a pound of butter.

A 10 fl. oz. can of pop is just a little larger than a 250 ml can of pop.

If the lines on your graduated cylinder are 1 ml apart, then your measurements should be no further out than 0.5 ml. Do you see why?

QUESTIONS:

1. How far out were you in your measured total volume?
2. Divide this by four to find your average error in each measurement.
3. Look at the scale on the graduated cylinder. How closely should you be able to measure volume?
4. It may be necessary to repeat this part of the experiment if your average error is too large.

UNITS OF VOLUME:

litre	ℓ
millilitre	ml
cubic centimetre	cm^3
cubic metre	m^3

VOLUME RELATIONSHIPS:

$1\,\ell = 1000$ ml
$1\,\ell = 1000\ cm^3$
$1\ ml = 1\ cm^3$
$1\ m^3 = 1000\,\ell$
$1\ m^3 = 1\ 000\ 000$ ml
$1\ m^3 = 1\ 000\ 000\ cm^3$

In the new metric system, commas are not used to mark off every three zeros. In Europe, a comma means what we mean by a decimal point. How could we ever have gotten in such a mess?

Which is more: a kilocent or a millidollar?
Just exactly what is a centidollar? Is our money metric?

1.4 Writing a Laboratory Report

This next investigation is really a test of your powers of observation. As you watch the sugar cube dissolve, write down everything that happens. Use short sentences and number them. Some students have described as many as twenty distinct, different things that happen. Be accurate. Missed or mixed-up observations will only confuse you and make the solving of the problem more difficult. You are the person who must be able to read, interpret, understand and communicate your results to others.

1.5 Investigation: Dissolving Sugar Crystals

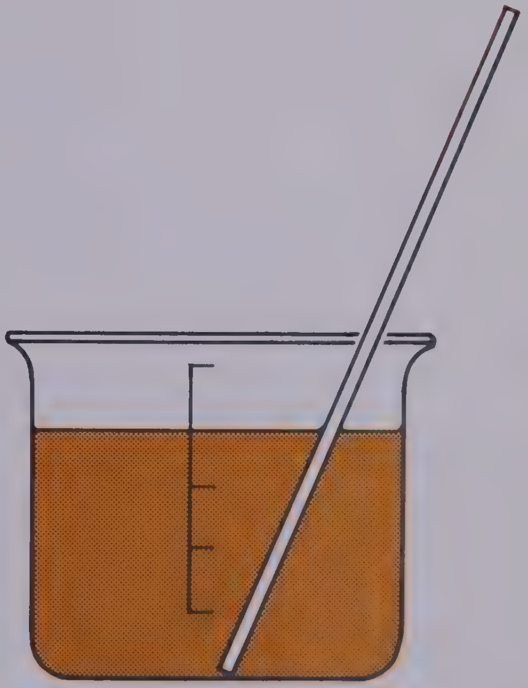
PROBLEM: WHAT HAPPENS TO SUGAR CRYSTALS WHEN THEY DISSOLVE?

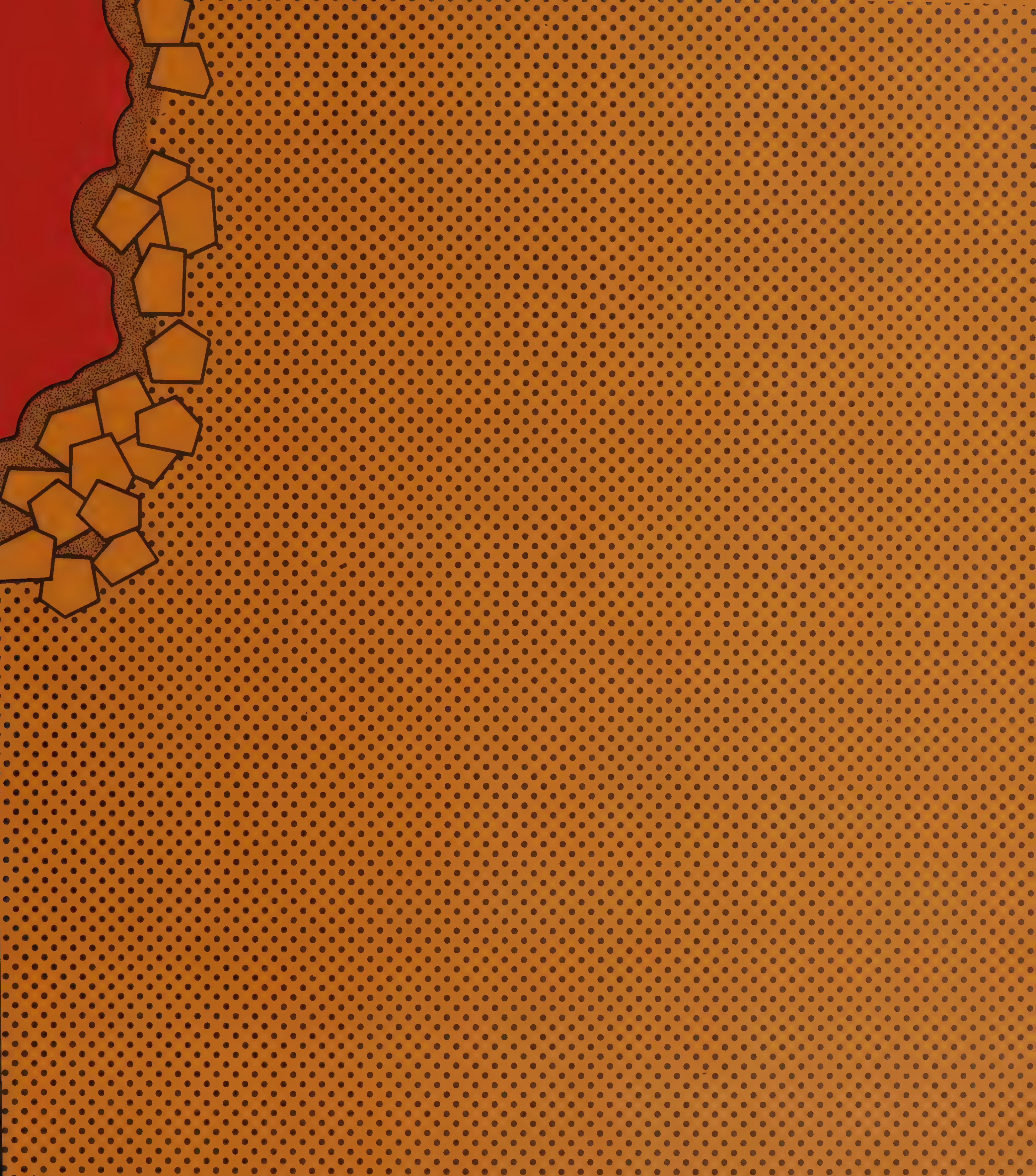
MATERIALS:

250 ml beaker
glass stirring rod
sugar cubes

PROCEDURE:

Fill the beaker with 200 ml of warm water from the tap. Wait until any cloudiness disappears, then drop in a sugar cube. Watch it as it dissolves. Write down everything that happens, everything that you think might tell you about the structure of either the water or the sugar. After about five minutes, when everything settles down, finish off the dissolving by stirring





with the glass rod. Study the final solution, looking for any signs of sugar. Repeat with another sugar cube to check your results.

QUESTIONS:

1. Which observations suggest to you that the sugar is no longer in the water after dissolving?
2. Which observations suggest to you that the sugar is somewhere in the water after dissolving?
3. Can you suggest some other simple experiments to find out what happened to the sugar?

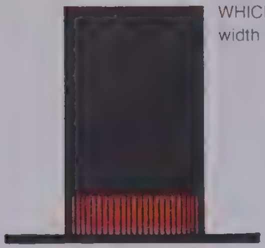
CONCLUSION:

Is the sugar still there or not, according to your observations?

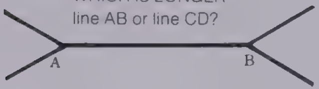
1.6 Can You Trust Your Senses?

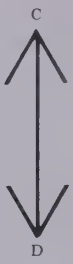
Making accurate observations can be tricky at times. Often, appearances are deceiving. Such quantities as size, volume, mass or even color are difficult to estimate accurately in every situation.

On this page you will find four tests of your skill in measuring distances. No rulers of any kind are allowed (no pencils, fingers, pieces of paper or other aids, please). Just look at the diagrams and decide. When you have finished, check your results with a ruler. You may be surprised! Naturally, you should use a ruler marked in millimetres when you check.

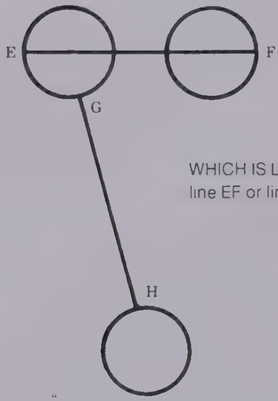


WHICH IS GREATER
width of the brim or height of the hat?

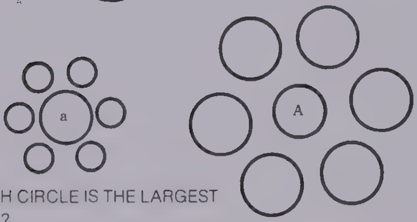




WHICH IS LONGER
line AB or line CD?



WHICH IS LONGER
line EF or line GH?



WHICH CIRCLE IS THE LARGEST
a or A?

1.7 Making Accurate Observations:

In your first look at dissolving sugar, the observations you made were mainly of things you could see. You did not measure a length or a temperature or a mass. Your observations used only your basic senses of seeing and, perhaps, hearing. We can extend these senses by using measuring instruments to make new and more accurate observations.

When sugar dissolves, does it disappear? If it did, would it still have mass? What would you expect to happen if the sugar did dissolve and disappear? What would you expect to happen if the sugar were still there after dissolving?

1.8 Weight and Mass

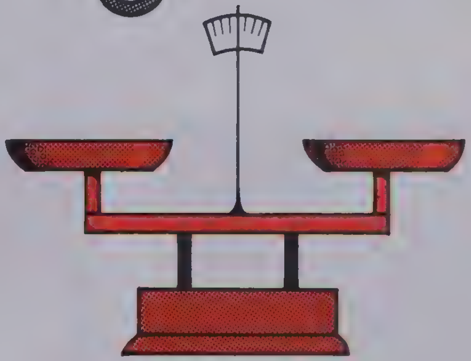
The weight of an object is the force of gravity of the Earth pulling down on it. The mass of an object is the amount of matter or "stuff" in it and is measured in units called kilograms.

Unfortunately, most of us use the word "weight" when we really mean "mass". When you step on a bathroom scale, it tells you how hard the Earth is attracting you. The scale is

In the British system, mass, weight and volume can all be measured in ounces. In the USA, these ounces are slightly bigger – or are they smaller? Which is heavier: an ounce of lead, an ounce of gold or an ounce of feathers? Did I remember to tell you that gold is measured in troy ounces, and not in ounces avoirdupois? I keep them straight by remembering that there are 437.5 grains in one ounce avoirdupois and 480 grains in one ounce troy. This difference is partly offset by the fact that there are only twelve ounces in a troy pound.

caught between you and the Earth and is compressed. If you went to the Moon and stepped on a scale there, you would weigh one-sixth as much. The Moon is smaller than the Earth and cannot pull as hard. Your weight is different on different planets or moons, depending on their size and what they are made of. Your weight would even be different at different places on the Earth - less on mountain tops, more in valleys, less at the equator and more at the North or South Pole (you are closer to the center at the poles because the Earth is not perfectly round–it bulges out at the equator). For this reason we will not talk about weight, but when you see data measured in grams then you will recognize that we are measuring mass.

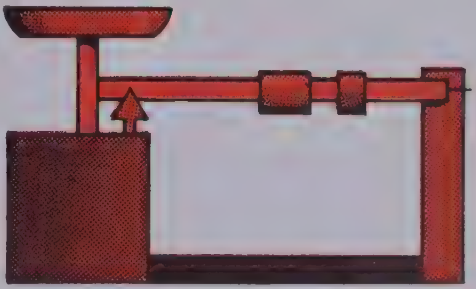
Your mass, the quantity of matter in you, would be the same in all these places, unless, of course, you ate too much while travelling from place to place.



Weight can be measured with a spring balance. The harder the Earth pulls down, the more the spring stretches. The same object would give a different reading if the force of gravity were to change.

Masses can be determined with an equal-arm balance by comparing a known mass with an unknown mass. If the objects on the pans have the same mass, then the scale will be in balance. They will be in balance no matter where you make the measurement.

Please follow your teacher's instructions carefully when using either the spring balance or the equal-arm balance—they are delicate instruments.



Mass is measured in the metric system in grams (g) and kilograms (kg). The "kilo" indicates a new unit 1000 times as big as the base unit.

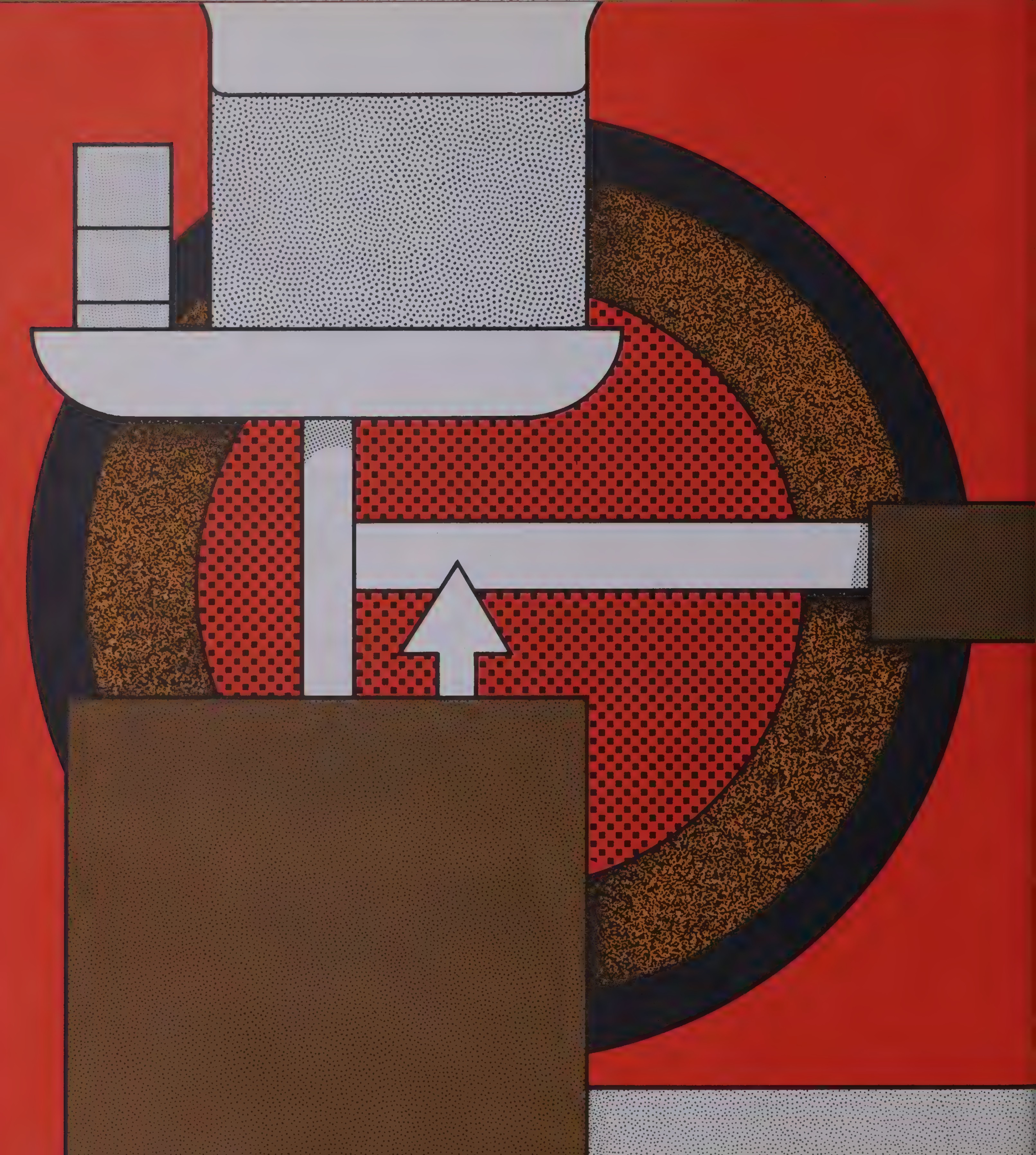
1 kg = 1000 g

MATERIALS:

100 ml graduated cylinder
balance
block of wood
lead mass
a cork
rubber stopper

PROCEDURE:

Estimate the mass of each object, record your estimates in grams, then find the actual mass on the balance. What is your mass in kilograms? What would it be in grams? Find the mass of 100 ml of water. Calculate the mass of 1 ml of water. Water is a special material in the metric system. Why?



1.9 Investigation: Mass / Dissolving

PROBLEM: DOES THE MASS OF A SUGAR SOLUTION CHANGE DURING DISSOLVING?

MATERIALS:

250 ml beaker	3 sugar cubes
glass stirring rod	equal-arm balance

PROCEDURE:

Fill the 250 ml beaker with 200 ml of warm water. Find the mass of three sugar cubes. Put the beaker of water, the stirring rod and the sugar cubes on the pan of the balance. Carefully adjust the balance so that it is balancing. Now, gently, lift the sugar cubes and put them in the water. As dissolving takes place, watch the balance to detect any change in mass. Finish off the dissolving with the glass rod, leaving it in the solution. If necessary, adjust the balance again.

OBSERVATIONS:

Be sure to include the following information: the total mass before dissolving, the total mass after dissolving and the change in mass during dissolving.

QUESTIONS:

1. What is the mass of three sugar cubes?
2. By how much did the mass of the solution change during dissolving?
3. What fraction of the sugar's mass disappeared or appeared in the experiment? Change this fraction to a percentage.
4. Check the results of the rest of the class. How many saw an increase in mass? How many saw a decrease in mass? How many saw the mass remain the same?
5. If all the sugar is still somewhere in the solution, what should happen to the mass as dissolving occurs?

CONCLUSION:

Is the sugar still there or not? What do your measurements indicate?

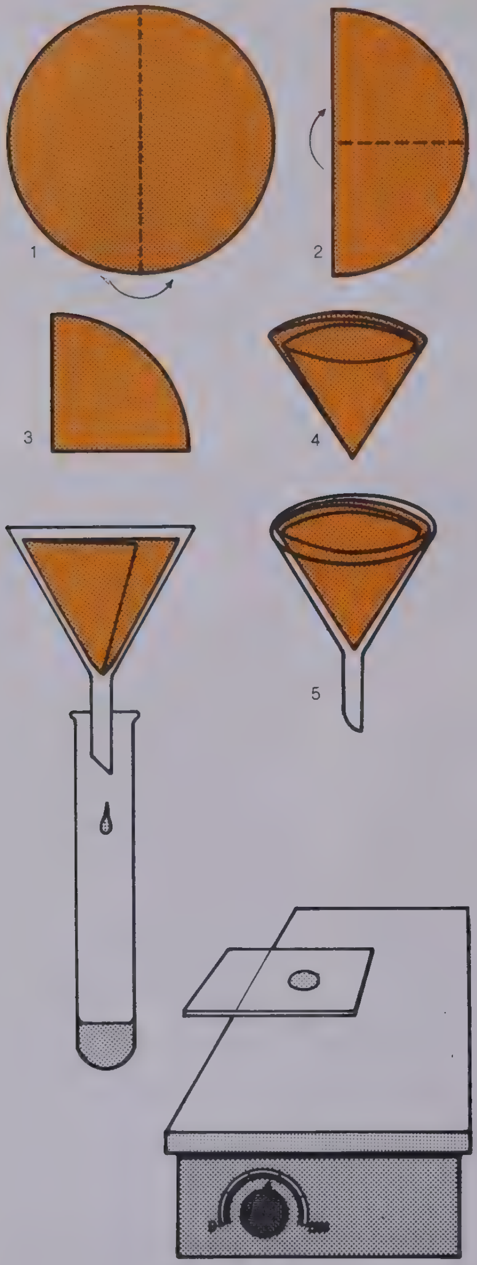
In the next investigation, other materials that dissolve in water will be examined and compared with sugar. Do all materials behave alike as they dissolve? What differences are there? What does this tell us about these kinds of matter?

If someone asks you how many pounds there are in a kilogram, ask him, with a smile, "troy or avoirdupois?"
Think Metric!

You might see a large unit of mass called the metric ton or tonne (t). It is just 1000 kg. It really should be called a megagram (Mg).

Sugar is very soluble. At room temperature, at least 200 g of it will dissolve in 100 ml of water.

In 1742, when Celsius first proposed his temperature scale, he made the freezing point of water 100°C and the boiling point of water 0°C. It didn't catch on, so he turned it upside down and now, 234 years later, we are stuck with it.
What *was* the name of that other scale, anyway?



1.10 Investigation: Other Solutions

PROBLEM: ARE OTHER SOLUTIONS SIMILAR TO SUGAR SOLUTIONS?

MATERIALS:

- 8-20 × 150 mm test tubes
- funnel with filter paper
- 4 microscope slides
- stirring rod
- magnifier
- hot plate
- salt
- potassium nitrate
- copper sulphate
- sugar

PROCEDURE:

Shake 2 g of each material in half a test tube of water until all the solid material has vanished. Filter each solution and examine the filtrate for any signs of solid particles. Look at the filter paper closely for any signs of material caught in it. Heat a drop of each solution and examine any solid left behind.

OBSERVATIONS:

Be sure to observe each sample of salt, potassium nitrate, copper sulphate and sugar for: the shape of one crystal, the color of the crystals and the color of the solution. Were any particles seen in the solution? Were any particles removed by filtering? Were any solids recovered by heating?

QUESTIONS:

1. Which observations suggest that the materials are no longer present after dissolving?
2. Which observations suggest that all the materials are present in their solutions?
3. When a material such as copper sulphate dissolves, is it still copper sulphate, or has it changed to something else? Which observations suggest the answer?

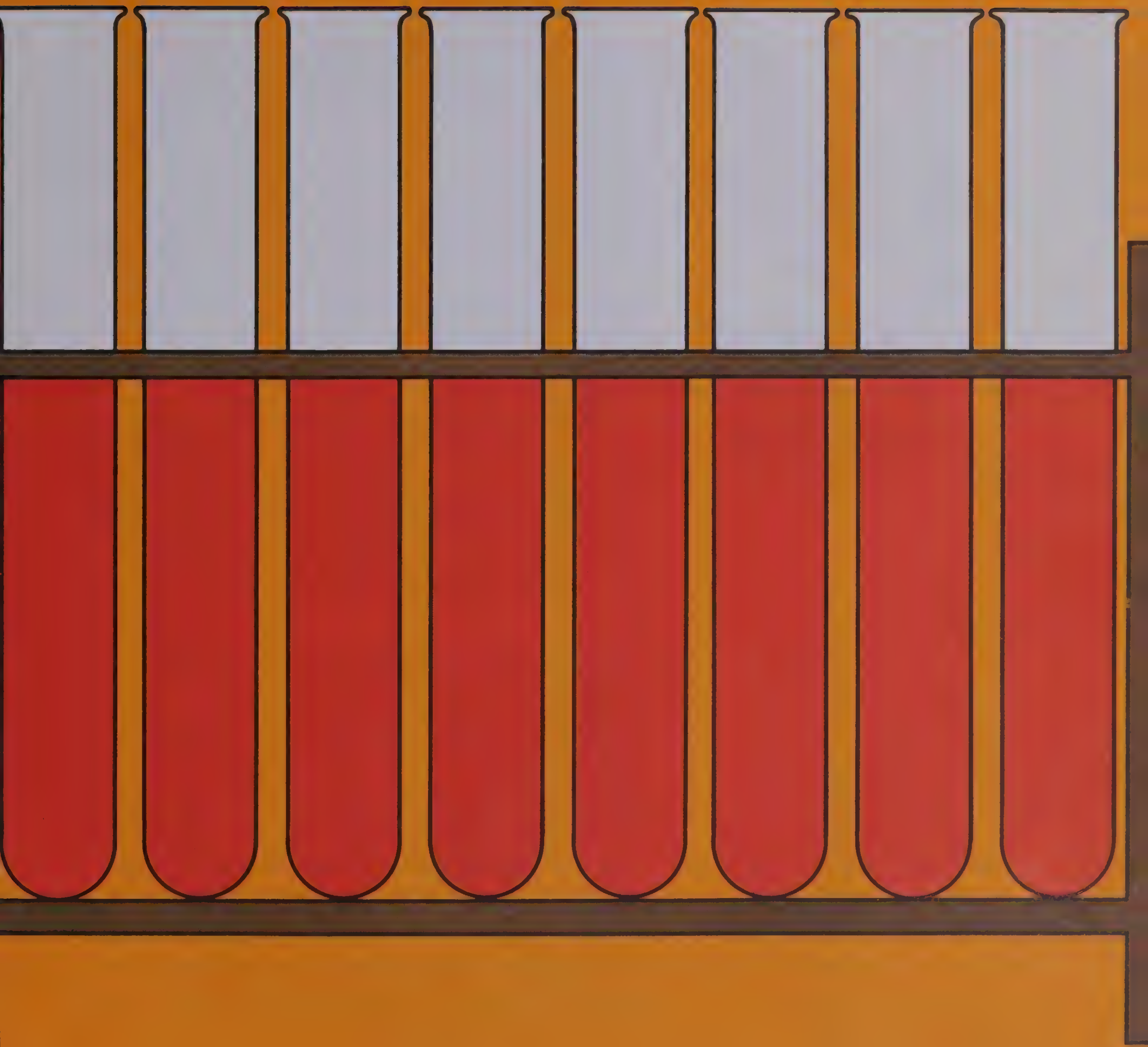
CONCLUSION:

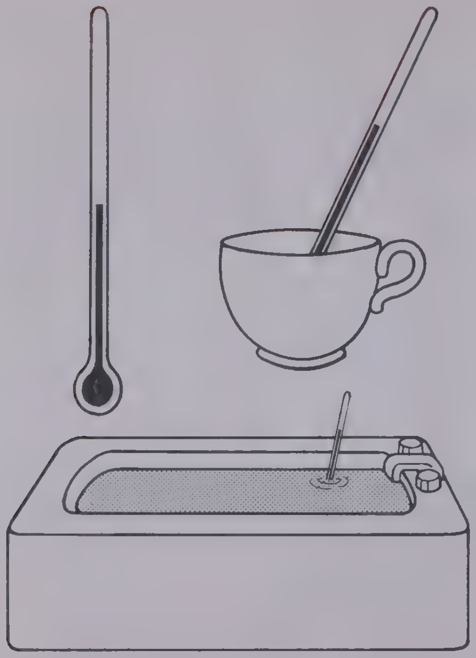
What are the common characteristics of solutions?

1.11 Saturated and Unsaturated Solutions

Sometimes there is a limit to the amount of material that will dissolve. A solution in which no more will dissolve is called a saturated solution. If more will dissolve, then the solution is unsaturated.

You are about to examine both kinds of solutions to see how they are affected by temperature. If you are not sure what temperature is, how it is measured or how it is different from heat, you should do the following investigation first.





Mercury freezes at –38.9°C.
Alcohol, possibly a safer material for thermometers, freezes at –117°C but boils at 78.5°C.

1.12 Heat and Temperature

Heating an object usually increases its temperature. Heat and temperature, however, are not the same. The heat needed to boil a beaker of water would have little effect on Lake Ontario. Concentrating heat produces a large temperature change. Spreading that same heat produces only a tiny temperature change.

Temperature measures heat intensity or heat concentration, not the total amount of heat.

Strangely, there is no instrument which can measure heat, but there are dozens of different kinds of thermometers for measuring temperature.

In the metric system, temperature is measured with a thermometer that reads in degrees Celsius (°C). Water freezes at 0°C and boils at 100°C.

MATERIAL:

thermometer

PROCEDURE:

Measure room temperature, then hold the bulb of the thermometer with your fingers and see what temperature you get.(Don't squeeze too hard.) Measure your body temperature. (Please don't put the thermometer in your mouth. Try under your arm.) Measure the temperature of cold water from the tap. Measure the temperature of hot water from the tap. Measure the outside temperature. Estimate average temperatures for each of the four seasons.

A salt mine near Goderich, Ontario, produces over 2 000 000 t of salt yearly. Chemical companies use it as a cheap source of sodium and chlorine. Many tons of it are used to melt snow on roads. About 2% of it is used for flavoring food.

Potassium nitrate is used in fireworks, fertilizer and food. It is used in making corned beef, among other things.

Copper sulphate is used to kill fungi, algae, microorganisms, weeds and vines. Please be careful with it.

1.13 Investigation: Temperature / Solutions

PROBLEM: HOW DOES TEMPERATURE AFFECT DISSOLVING?

MATERIALS:

13 × 100 mm test tube	ring clamp
2-250 ml beakers	Bunsen burner
test tube holder	thermometer
retort stand	asbestos pad
potassium nitrate	

PROCEDURE:

Set up a water bath to heat the solution in the test tube (see diagram). Fill the other beaker with ice-cold water. Put 5 ml of cold water in the test tube. Measure out 3 g of potassium nitrate and add it to the water. Try to dissolve all of it by shaking it (with your thumb over the end). This should produce a saturated solution with some crystals left in the bottom of the test tube. By shaking, heating in the water bath, measuring the temperature, shaking again, heating again and so on, try to find the exact temperature at which all the crystals dissolve.

When you have dissolved all the crystals, keep heating for another minute. Then reverse the experiment by cooling the test tube in the beaker of cold water. Something remarkable should happen! Try to measure the temperature at which it starts to happen.

QUESTIONS:

1. Does heat help or hinder dissolving?
2. Is heat necessary for dissolving? (If you cooled a solution far below room temperature, what would happen?)
3. If you have a saturated solution at 25°C and you heat it, what kind of solution will you have then?
4. If you have a saturated solution at 50°C and you cool it, what will happen? What kind of solution will you have at the new, lower, temperature?

CONCLUSIONS:

1. What effect does heat have on dissolving?
2. How does a saturated solution stay saturated if it is heated?
3. How does a saturated solution get rid of extra dissolved material as it cools?

1.14 Investigation: Solutions / Heat

PROBLEM: AS A MATERIAL DISSOLVES, DOES IT ABSORB OR RELEASE HEAT?

MATERIALS:

13 × 100 mm test tube
thermometer
ammonium chloride
copper sulphate
potassium nitrate
sodium thiosulphate
sodium sulphate

PROCEDURE:

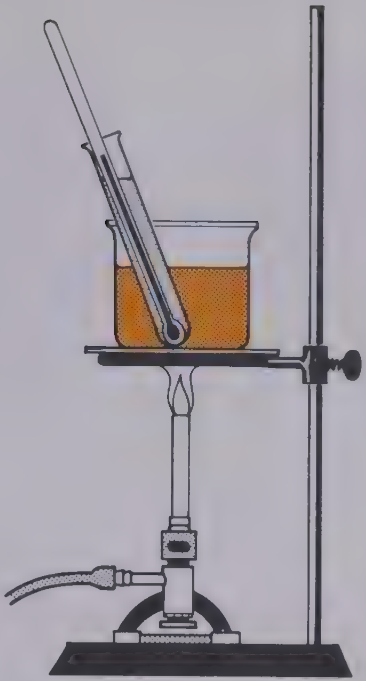
Measure out into the test tube 5 ml of water which is exactly room temperature. Measure out 2 g of one of the materials. Measure the water temperature, pour in the material, shake it a few times to dissolve some or most of it, then quickly measure the temperature again.

OBSERVATIONS:

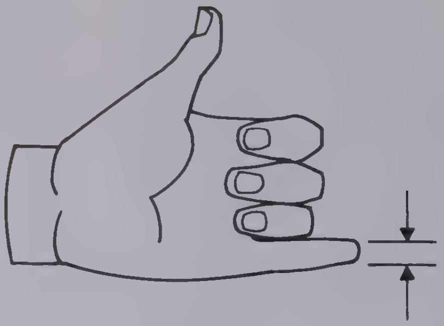
Include the following data for each of the samples: What was the temperature before dissolving? What was the temperature after dissolving? How much did the temperature change?

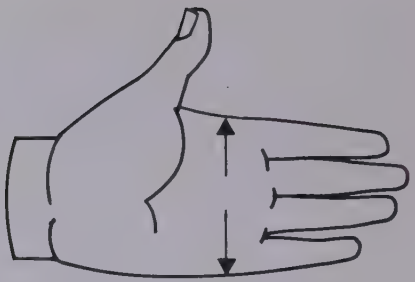
QUESTIONS:

1. If the water temperature decreases during dissolving, is the dissolving material taking in or giving off heat?
2. When an ice cube melts, does it absorb or release heat? Do dissolving substances act in a similar way?
3. In the last experiment, you found that extra heat allows more material to dissolve. Does this suggest that a dissolving substance absorbs heat or releases heat?



Canada produces about 500 000 t of sodium sulphate each year. Most of it comes from a few lakes in Saskatchewan. In the summer, lake water is pumped into reservoirs. By late fall, a layer of sodium sulphate covers the bottom of the reservoir. The remaining water is pumped back into the lake and machines dig up the sodium sulphate. Why does the lake water release the sodium sulphate?





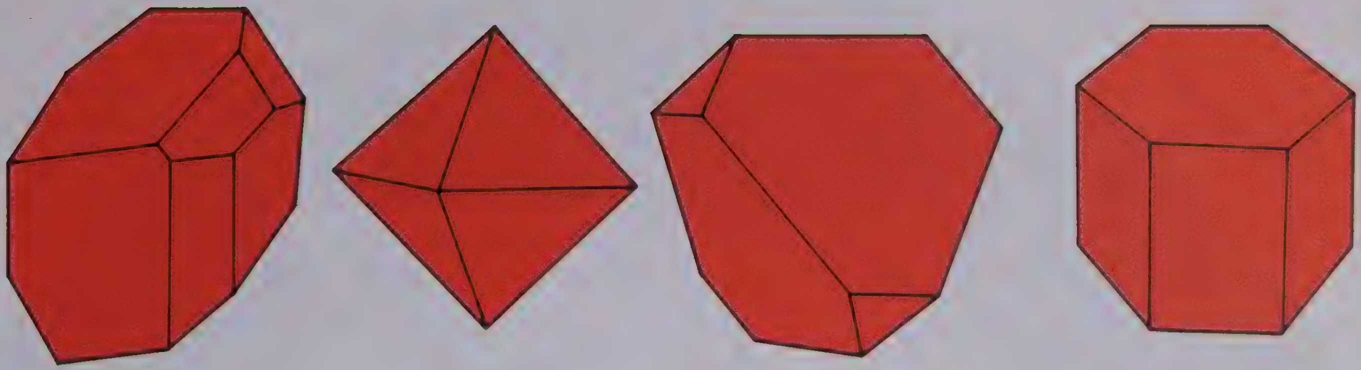
Ammonium chloride is commonly known as "sal ammoniac". The ancient Egyptians used ammonium chloride from the soot of camel dung found near the temple of Jupiter Ammon. They called it salt of Ammon or sal ammoniac. I wonder what they used it for?

Ammonium chloride is the major ingredient of the paste inside flashlight batteries and is also used as a soldering flux. I don't think the Egyptians had either flashlights or soldering guns.

4. What would you expect to happen if a solution started to form crystals, instead of dissolving more? Would the temperature of the solution rise or fall?

1.15 The Metric System

UNITS OF LENGTH:		
millimetre	(mm)	1 m = 1000 mm
centimetre	(cm)	1 m = 100 cm
metre	(m)	
kilometre	(km)	1 km = 1000 m
UNITS OF VOLUME:		
cubic centimetre	(cm^3)	1 ml = 1 cm^3
millilitre	(ml)	1 ml = 1000 mm^3
litre	(ℓ)	1 ℓ = 1000 ml
cubic metre	(m^3)	1 m^3 = 1000 ℓ
UNITS OF MASS:		
gram	(g)	1 kg = 1000 g
kilogram	(kg)	
UNITS OF TEMPERATURE:		
degree Celsius	(°C)	



1.16 Summary

1. A pure substance consists of only one kind of matter.
2. A mixture contains more than one kind of matter.
3. A solution is a special kind of mixture of a solute dissolved in a solvent.
4. A saturated solution will not hold any more dissolved material.
5. An unsaturated solution will dissolve more material.
6. Measuring instruments extend the senses to make more accurate observations.
7. Volume is the amount of space an object fills. It can be measured in millilitres with a graduated cylinder.
8. Weight is the downward pull of gravity on an object. It is a force.
9. Mass is the amount of matter in an object. It is measured in grams or kilograms with a balance.
10. Temperature measures the intensity or concentration of heat, not the total amount of heat in an object. It is measured in degrees Celsius with a thermometer.
11. Crystals seem to have naturally flat sides, straight, sharp edges and equal angles.

Sodium sulphate is commonly called "Glauber's salt" but was once known as "Glauber's Miraculous Salt" and was swallowed to clean out the system – all of it.

Sodium sulphate is used now in pulp and paper mills in the bleaching of the pulp to make it white instead of wood colored. This substance is one of several possible pollutants from pulp and paper mills.

Sodium thiosulphate is known to photographers as "hypo" and is used by them in film development. After the image has been developed, hypo solution dissolves any remaining light-sensitive compounds. The film can now be exposed to the light without harm and dried. The used hypo solution was at one time poured away, until someone realized that it is a valuable source of silver. The light-sensitive compounds have silver in them.

1.17 Further Investigations

1. Prepare a small amount of saturated potassium nitrate solution. Drop a copper sulphate crystal in. Does it dissolve? What does this mean?
2. Prepare a saturated solution of sugar cubes. Start with 50 ml of water and heat gently to dissolve as much sugar as possible.
3. Saturate a salt solution at room temperature. (3 g of salt in 5 ml of water.) How much more salt will dissolve if the solution is heated right to boiling?
4. Start with 5 ml of ice water and several 1 g samples of potassium nitrate. Find the temperature at which the first sample dissolves, then add the next. Heat until it dissolves. Draw a graph with the amount dissolved on the vertical axis and the temperature of dissolving on the horizontal axis.
5. Heat crushed copper sulphate crystals in a test tube until the blue color disappears completely. What seems to be given off? Cool the material that is left. Measure the temperature change as this material dissolves in 5 ml of water. What seems to have happened here?
6. Is tap water a pure substance or a solution? Look at a drop of tap water under a microscope. Dry up a drop of tap water on a slide and examine it for any residue. Scrape the inside of a kettle and examine any residue carefully. Can filtration remove material dissolved in water? Will it settle out? How could it be removed?

1.18 Review

1. Give three examples of pure substances not mentioned in the text.
2. Classify each of these as a pure substance or a mixture: bread, milk, air, a penny, a quarter, a nail, sugar, a cloud, mercury, water.
3. Give three reasons for thinking that sugar does not disappear, but is still present in a sugar solution.
4. What is the volume of each of the following blocks of wood, in cubic centimetres? Round off your answer to the nearest cubic centimetre.

	LENGTH (cm)	WIDTH (cm)	HEIGHT (cm)
(a)	100	50	20
(b)	16	24	310
(c)	312.5	13.9	77.6
(d)	6112.3	416.8	25.9

Salt Water Solutions

There is much talk of water pollution these days, as if it were something new that was just now becoming a problem. However, over 98% of the Earth's water supply is now, and always has been, polluted. You cannot drink it, irrigate farmland with it or use it in car radiators or batteries. We are talking about the salt water in the oceans, which cover over 70% of the Earth's surface.

Of the remaining 2%, 98% is frozen, locked into the great ice caps covering the Antarctic and Greenland. This leaves only 1 part in 2500 of the Earth's water available as fresh water.

You can make your own ocean salt water by dissolving 3 g of salt in 100 ml of water. Real salt water has about 0.3 g of various other substances dissolved in it, but this won't make much difference to us here. Try your own taste test.

What can be done to purify salt water? From your study of solutions, you know it would be useless to filter it. The dissolved salt will pass through even the finest filter. Leaving the salt water to settle in tanks does not help. The salt is dissolved and will never settle out. This is characteristic of solutions.

In some countries there are small plants which convert salt water to fresh water by distillation. The salt water is boiled, steam is produced, the steam is caught and cooled and changes back to pure water. The salt is left behind in the original container. This is an expensive process. Salt water is especially hard to boil, and the heat energy needed is more than most countries can spare.

Nature uses the same process to produce fresh water. The sun's heat evaporates ocean water and carries the water vapor away (hot air rises). The vapor starts to cool and condense, first to form clouds and then rain drops. The water in the atmosphere falls as rain and is replaced by evaporation about every twelve days.

It is not a very efficient process. Most rain (over 70%) falls on oceans and is immediately polluted again. Only a small fraction of the remainder is used. The rest runs down streams and rivers back into the ocean. Plainly, the supply of fresh water is limited by the power of the sun and by the cost of heat energy for distillation plants.

The questions in the Review section of the text are designed for use at home, to allow you to test yourself on the work covered in class. These kinds of problems are sure to appear on tests.

5. What is the volume of each of the blocks of wood in question 4, in litres? Round off your answer to the nearest litre.
6. How many millilitres are there in each of these volumes?
   (a) 5 ℓ
   (b) 5.1 ℓ
   (c) 5.135 ℓ
   (d) 1.072 m^3
   (e) 16 m^3
   (f) 72.957 m^3
7. How much volume would each of these amounts of water occupy?
   (a) 250 g (b) 512 g (c) 29.36 g (d) 6 kg (e) 0.56 kg
8. A cube of wood measures 20 cm along each side.
   (a) How many millimetres does it measure along each side?
   (b) How many metres does it measure along each side?
   (c) What is the volume of the cube in cubic centimetres?
   (d) What is the volume of the cube in cubic millimetres?
   (e) What is the volume of the cube in cubic metres?
9. A certain school measures 4 m by 100 m by 40 m.
   (a) What is the volume of the school in cubic metres?
   (b) If there are 600 students in the school, how much volume is each allowed?
   (c) Find the total volume of your classroom and divide by the number of people in it to find the volume per person.
10. Which is more, 4.5 ℓ, 3900 ml, or 5200 cm^3?
11. A graduated cylinder is filled with 45 ml of water. An object that can float is dropped in, which brings the water level up to 70 ml. The object is pushed under the water with a pencil to bring the water level up to 85 ml.
   (a) What is the total volume of this object?
   (b) What volume of the object is under the water when the object is floating?
   (c) What fraction of the object is submerged when the object is floating?

1.19 Instructional Objectives

The list of Instructional Objectives is especially useful at test time. Go through them one by one, making sure that you understand each one and that you can do what is described. If you cannot, then go back to your notes, your textbook or your teacher for further study.

1. Given a metric ruler, to measure distances in millimetres, centimetres or metres, accurate to the nearest millimetre.

2. Given a metric ruler, to find the volume of a rectangular block of material in cubic centimetres or millilitres.

3. Given a graduated cylinder, to measure the volume of a sample of liquid, in millilitres, to the nearest millilitre.

4. Given a graduated cylinder, to find the volume of a small irregular object by the water it displaces.

5. Given a balance, to find the mass of an object in grams, to the nearest tenth of a gram.

6. To describe the difference between mass and weight.

7. To describe the difference between mass and volume.

8. For a particular solution, to identify the solute and solvent.

9. To write a laboratory report, using the proper headings, in complete sentences, in legible writing, so that the teacher or another student can read and understand what was done in an experiment.

10. To change a mass measured in grams to kilograms, and the reverse.

11. To state the mass of a sample of water in grams, if the volume in millilitres is given, and the reverse.

12. To describe the effect of dissolving on the total mass and volume of the solute and solvent.

13. To distinguish a water solution from a sample of pure water in at least two ways.

14. To state at least two characteristics shared by water solutions and pure water.

15. To describe the difference between unsaturated and saturated solutions.

16. To describe the effects of heating or cooling on both saturated and unsaturated solutions.

17. Given a thermometer, to measure the temperature of an object in degrees Celsius, to the nearest degree.

18. To state various common temperatures in degrees Celsius, including room temperature, winter temperatures, summer temperatures, body temperature.

19. To state whether a substance absorbs heat or releases heat as it dissolves, given the temperature of the solvent before and after dissolving, and the reverse.

When you are changing from one metric unit to another, make sure that your answer is reasonable.

Can 25 m = 0.025 mm? Of course not! 25 m is a large distance; 0.025 mm is a very small distance.

1.20 Glossary

- Celsius scale
- centimetre
- crystal
- dissolve
- gram
- gravity
- heat
- kilogram
- litre
- mass
- matter
- melt
- millilitre
- mixture
- pure substance
- saturated solution
- scientific method
- solute
- solution
- solvent
- structure
- temperature
- unsaturated solution
- volume
- weight

Theories of matter

2.1 The Structure of Matter
2.2 Make Up Your Own Answer!
2.3 Two Theories
2.4 Did You Understand?
2.5 Other Kinds of Mixtures
2.6 Investigation: Solutions and Other Mixtures
2.7 Testing a Theory
2.8 Investigation: Volume of Mixtures
2.9 Investigation: Volume of Solutions
2.10 Does 1 + 1 Always Equal 2?
2.11 Investigation: Composition of Liquids
2.12 Summary
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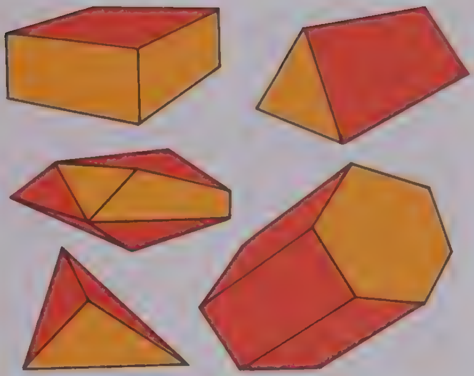
2.1 The Structure of Matter



As we studied matter dissolving in Chapter One, there were, no doubt, many things you saw which you could not explain. Some of the things which might be puzzling are:

1. How does water cause a sugar cube to disintegrate?
2. How can something which seems to disappear still have mass?
3. Why do more crystals dissolve if the solution is warmed?
4. Why do crystals form, as a saturated solution forms?
5. Why do crystals have flat sides and straight edges?
6. How do crystals absorb heat as they dissolve? Where does the heat go? What is heat?

2.2 Make Up Your Own Answer!

About 2500 years ago, Thales of Miletus said that all matter is really water in different forms: solid, liquid or gas. If sugar is a kind of solidified water, then of course it would seem to disappear as it dissolves.

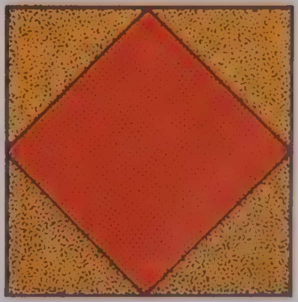
Thales (624-546 BC) once fell into a well as he walked along looking up at the stars

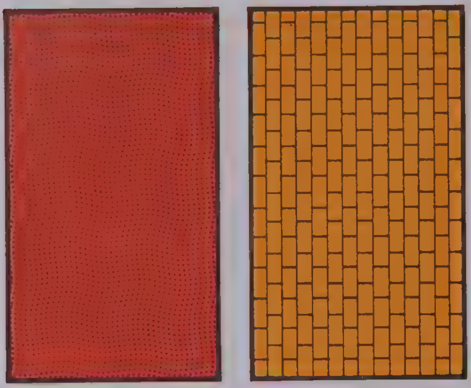
About 100 years later, Aristotle suggested that four basic types of matter–earth, air, fire and water–combine to make all the other kinds of matter. Each of the four elements was supposed to possess two of four basic properties–hot, cold, wet and dry. A solution of water (wet and cold) and sugar (cold and dry) would definitely be cold, but there would be a contest between wet and dry (will more crystals form or will they all dissolve?).

Aristotle (386-322 BC) also taught that a large rock always falls faster than a small rock. It is too bad that he never tried it. Have you?

Another theory was suggested by Leucippus and Democritus. They thought that matter was built out of particles held together by tiny hooks. Different kinds of matter would have different kinds of particles. Also, the hooks holding iron particles together would be much stronger than the hooks holding a piece of cheese together. The particles would be very small, for none could be seen by the naked eye or through the strongest microscope. This theory could explain what happens in dissolving: the sugar particles are pulled apart by water particles. The sugar particles would be in the solution, but would be too small to see.

The Greeks had no way of proving practically which of these and other theories was correct. They did not realize that by doing experiments they could get the necessary proof.





2.3 Two Theories

The Greeks developed two kinds of theories of matter. The supporters of one kind of theory believed that matter is continuous, that a piece of matter fills completely the space it occupies. A glass of water is one chunk of water. A piece of wire is one piece of wire. The smallest raindrop is still a complete piece of water.

Supporters of the other theory believed that matter is particulate, that is, made of particles, so that a piece of wire is really billions of little particles joined together and a glass of water is nothing more than a glass of matter particles much smaller than, but similar to, sand.

What do you think? Do you believe that matter is continuous or particulate?

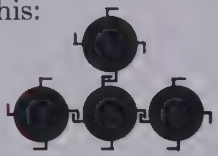
2.4 Did You Understand?

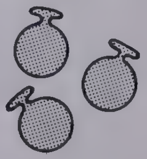
For this question, we will call an object continuous if it *seems* to be all one piece, and any object which *seems* to be composed of a number of pieces will be labelled particulate. If examined under a very powerful microscope, these continuous objects might turn out to be particulate. We will only use observations made with the naked eye.

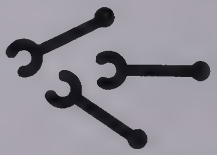
1. Observe these objects, then classify them as continuous or particulate:
   - (a) a length of copper wire
   - (b) a jar of sand
   - (c) a bowl of jelly
   - (d) a length of chain
   - (e) a freight train
   - (f) a picture of a train
   - (g) a marble
   - (h) a beaker of marbles
   - (i) a glass of water
   - (j) a snake
2. Those who supported the continuous theory said that if you magnified a glass of water more and more and more, it would still look like water. What would those who believe in the particle theory say?

Not even the most powerful of microscopes, magnifying a drop of water more than 1000 times, reveals any sign of water particles.

3. Lucretius, a Greek philosopher who lived about 100 AD, might have drawn pictures of his tiny particles of matter like this:







   - (a) Which kind of particles do you think would represent the iron particles in a piece of iron?
   - (b) Which kind do you think would represent the water particles in a glass of water?
   - (c) Which kind do you think would represent the particles of a piece of string?
   - (d) Draw the kind of particles you would use to represent those in a rubber band.
   - (e) Suggest another material for each kind of particle. Be prepared to give a reason for your choice.
4. So far, which theory do you believe is correct?

2.5 Other Kinds of Mixtures

Solutions are not the only kind of mixture. In some mixtures, the solid material does not entirely disappear. In others, there is hardly any dissolving at all. In suspensions, we can see large undissolved particles, while in dispersions, we can see smaller particles only.

Perhaps these other kinds of mixtures can help you to decide what happens during dissolving. Perhaps they will give you clues to help decide whether matter is continuous or particulate. From now on, you should pay close attention to any observations that might show which theory of matter is correct.

Could a solution be composed of particles too small to see? Would the water have particles too?

2.6 Investigation: Solutions and Other Mixtures

PROBLEM: DO OTHER KINDS OF MIXTURES ACT LIKE SOLUTIONS?

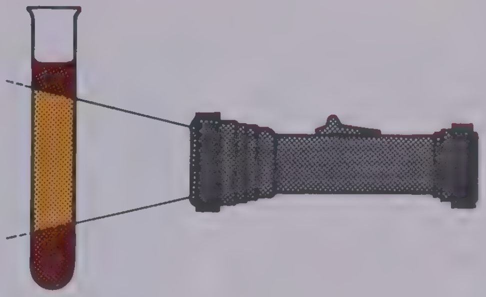
MATERIALS:

6-20 × 150 mm test tubes
test tube rack
funnel
filter paper
light source
copper sulphate
liquid laundry starch
soil

Should large particles or small particles scatter light more?

PROCEDURE:

Make mixtures of water with copper sulphate crystals, liquid laundry starch and fine soil. Hold each mixture in a light beam and examine the shadow to see how well light passes through. Let half the mixture stand for awhile to see if any material settles to the bottom, and filter the rest. Examine the residue and the filtrate.



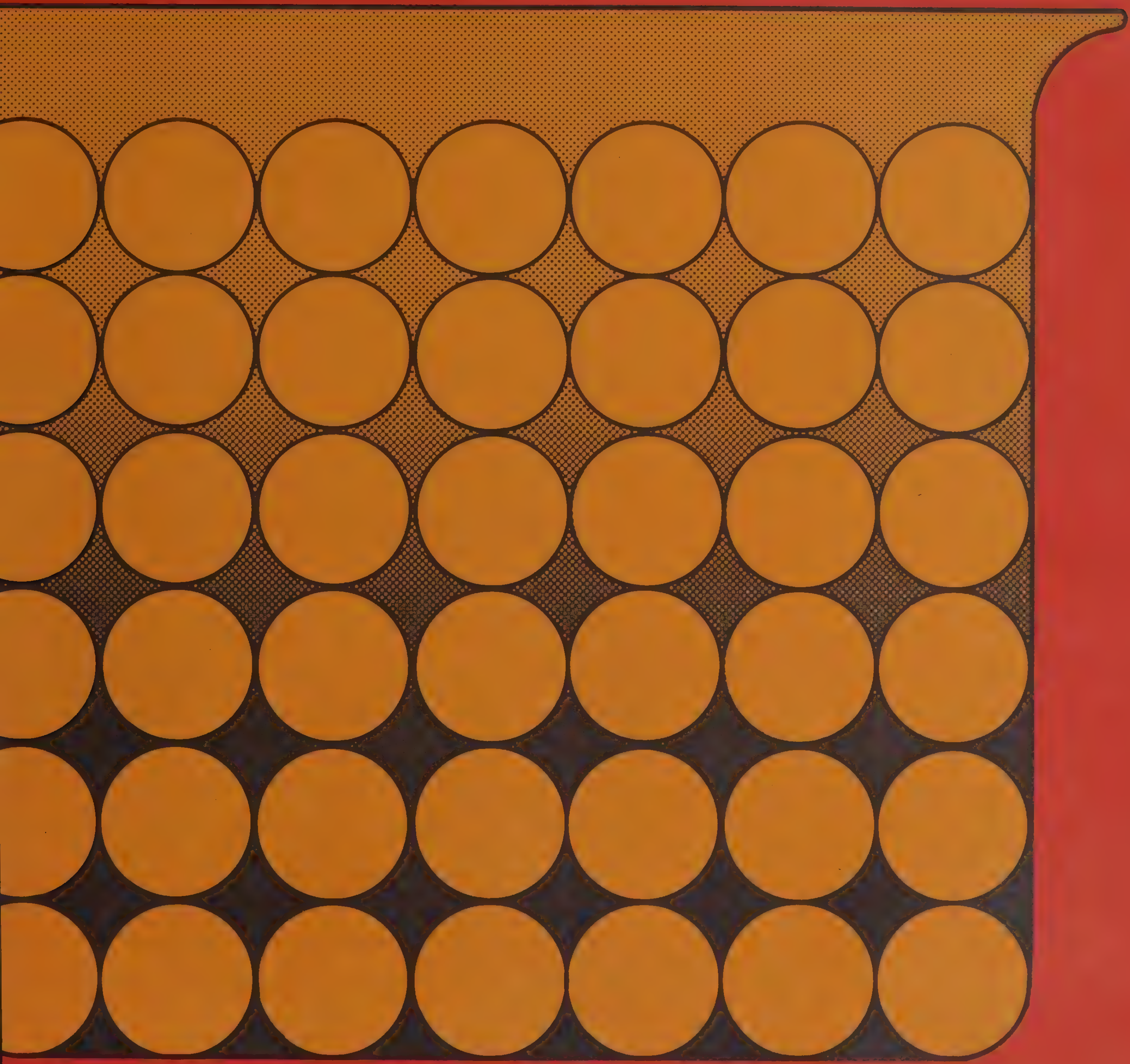
OBSERVATIONS:

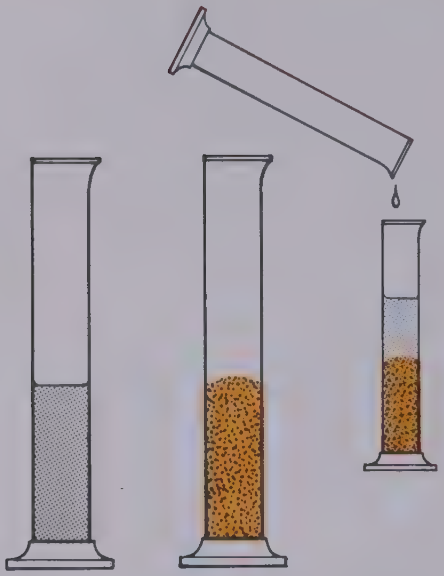
1. Are particles visible in the mixture?
2. Does the mixture transmit light?
3. Does any solid settle out?
4. Is the solid removed by filtering?
5. Classify each by particle size (large/medium/small).
6. Classify each by name (solution/dispersion/suspension).

A mixture which scatters a beam of light, instead of absorbing it or letting it go through, is said to be showing the "Tyndall effect". Do any of your mixtures show the Tyndall effect?

QUESTIONS:

1. Which theory of matter do these observations support?
2. According to the particle theory, why do substances disappear when they dissolve?
3. According to the continuous theory, why do substances disappear when they dissolve?





Why should the mixture of sand and water have the same mass as the mass of the water plus the mass of the sand?

2.7 Testing a Theory

Once you have a theory, the next step is to invent experiments to test the theory. Our particulate theory says that matter is piles of tiny particles. If you look at a pile of particles, such as a beaker of sand, you can see tiny spaces between particles. If you push down on the sand, you can make these spaces smaller. If you pour the sand into a beaker of marbles, the one kind of particle is able to fill the spaces between the marbles, which represent another kind of particle.

If all materials are actually made of particles, shouldn't something special happen whenever two materials are thoroughly mixed, such as during dissolving? We already know that mass remains constant during dissolving. Does volume also remain constant?

What about the continuous theory? If all matter were continuous, would you expect it to have tiny spaces in it? Would you expect a change in volume when two materials are mixed?

Do you see that the two theories predict two different things will happen during dissolving? By doing the following experiment, perhaps we can decide which theory is right.

2.8 Investigation: Volume of Mixtures

PROBLEM: IS THE VOLUME OF A MIXTURE THE TOTAL OF THE VOLUMES BEFORE MIXING?

MATERIALS:

2-100 ml graduated cylinders
sand

PROCEDURE:

Fill one cylinder with 50 ml of sand. Fill the other with 50 ml of water. Pour the water into the sand and measure the total volume.

OBSERVATIONS:

1. What is the volume of the sand?
2. What is the volume of the water?
3. What is the volume of the mixture?

QUESTIONS:

1. Did the volumes add up?
2. When you measured the volume of the sand, did you really just measure sand?
3. If water is also a pile of particles, did the water volume include only water?
4. What is the volume of the spaces between the sand particles before mixing?

2.9 Investigation: Volume of Solutions

PROBLEM: IS THE VOLUME OF A SOLUTION THE TOTAL OF THE VOLUMES BEFORE MIXING?

MATERIALS:

100 ml graduated cylinder
rock salt

PROCEDURE:

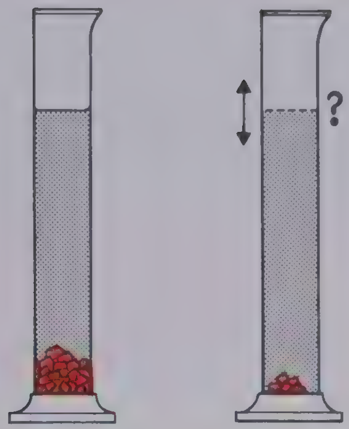
Fill the cylinder with about 50 ml of rock salt. Add enough water to bring the total volume to exactly 100 ml. Shake for several minutes to dissolve as much salt as possible. Measure the volume again.

OBSERVATIONS:

1. What is the volume before mixing?
2. What is the volume after mixing?

QUESTIONS:

1. Shake a cylinder filled with 100 ml of water. Was there enough loss in volume to account for your above observations?
2. Does rock salt take up as much volume after dissolving as before?
3. Which theory of matter do these results support?
4. According to this theory, why is there a loss in volume?
5. If rock salt particles and water particles were the same size, would the total volume still change?



If there really are particles in a crystal, with spaces between them, what do you think might be in those spaces?

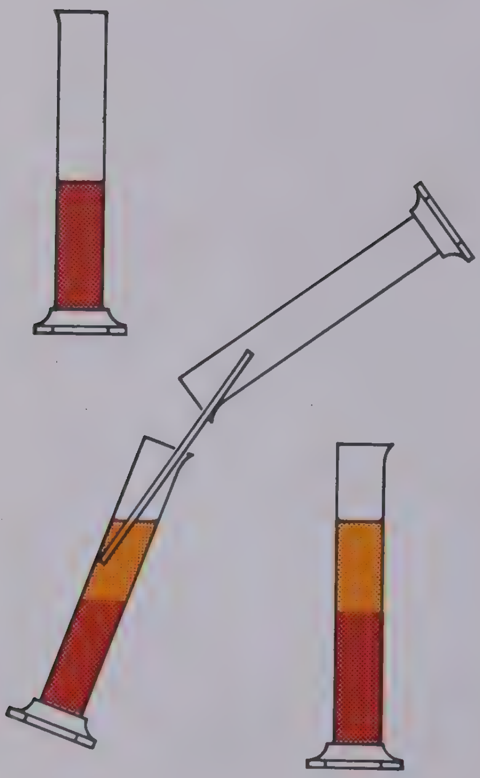
2.10 Does 1 + 1 Always Equal 2?

In the last investigation, you probably found that some of the original volume of the matter disappeared when dissolving took place. It is difficult to explain this using our continuous theory, but easy if we assume that matter is made of tiny particles with spaces in between. Some people complain that there are air bubbles trapped in the salt crystals which are removed by the shaking, and therefore the volume is reduced. Maybe, or maybe not. Why not try another pair of materials to see if the volume still decreases?

If you add one pile of hay to one pile of hay, don't you still just have one pile of hay?

Fill a glass of water really full, right up to the top. Now add pennies, one at a time, carefully. How much space was there still to be filled in the glass?

Two liquids can form a solution, just as easily as a solid and a liquid can. In the following investigation, the volume of a solution of alcohol and water is measured before and after mixing. Do you think some volume will disappear? Try it!



2.11 Investigation: Composition of Liquids

PROBLEM: DO LIQUIDS HAVE SPACES IN THEM THAT CAN BE FILLED BY OTHER LIQUIDS?

MATERIALS:

100 ml graduated cylinder
250 ml beaker
glass stirring rod
alcohol

PROCEDURE:

Fill the graduated cylinder with 50 ml of water. Pour alcohol from the beaker down the glass rod into the cylinder. If you are careful, you will be able to see a line dividing the water from the alcohol. Measure the volume before mixing as accurately as you can. (The volume should be somewhere between 90 and 100 ml.) Now mix the two together by shaking or stirring. Be careful not to lose any liquid.

OBSERVATIONS:

1. What is the volume before mixing?
2. What is the volume after mixing?

QUESTIONS:

1. If matter is continuous, can the volume of liquid change after mixing?
2. If matter is particulate, can the volume change after mixing?
3. If alcohol particles were the same size as water particles, would the volume change?
4. Did the water level go down because alcohol evaporated? Pour out a cylinder of alcohol and watch it for a few minutes.
5. Did the liquid level go down because of liquid spilled or lost in the mixing? Try the experiment again with just water in the cylinder. How much is lost if you are careful?
6. Can you think of any other reasons why the total volume decreases? Can you think of simple experiments to check whether these reasons are the correct ones?

2.12 Summary

1. A theory is a suggested answer to a problem. A theory can be used to predict what will happen in an experiment. Doing the experiment will decide whether the theory is right or not. No theory can be accepted as fact until it can explain every observation of every experiment.

2. The particulate theory of matter states that matter is made of tiny invisible particles.

3. The continuous theory of matter states that matter is all one piece with no holes or spaces.

4. Solutions, dispersions and suspensions are all mixtures.

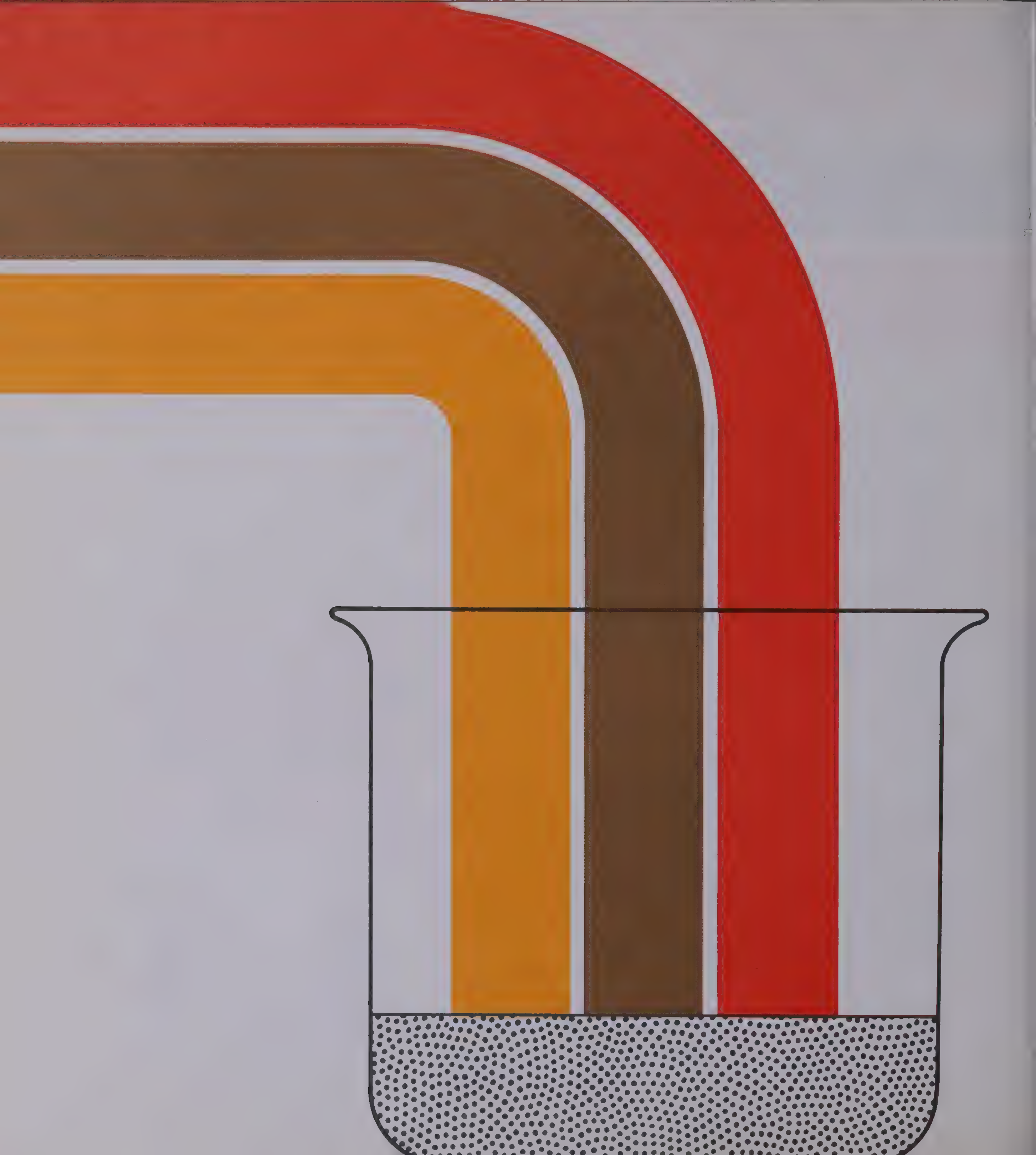
5. In suspensions, the particles are large enough to be filtered out or settle to the bottom of the container.

6. In dispersions, the particles are too small to be filtered out or to settle to the bottom of the container, but are large enough to block a light beam and scatter light in all directions.

7. If the particle theory is correct, a solution has even smaller particles than a dispersion, too small even to scatter a beam of light.

8. In solutions, the volume after mixing is usually less than the volume before mixing. Which theory explains this best?

When an inexperienced scientist is faced with a problem, the suggested answer to that problem might be called a "guess". The suggested answer of an experienced scientist is called a "hypothesis". After a few investigations have been done to test a hypothesis, and it still seems true, it may be called a "theory". Some theories have been believed to be true for so long that the general public accepts them as fact. But a true scientist knows each theory must withstand the test of experiment, and new experiments are constantly being done. The theory must explain them all, or it is wrong. In science, you know for sure when you are wrong, but you can never be quite sure that you are correct.



2.13 Further Investigations

1. Is there a volume change when sugar dissolves? (Try granulated sugar instead of sugar cubes, which obviously have spaces between crystals. We want to know whether there are spaces between the particles that are supposed to form each crystal.)
2. Does the amount of alcohol added make a difference? Try various combinations of alcohol and water that add up to 100 ml, such as 10 ml water, 90 ml alcohol, then 20 ml water, 80 ml alcohol and so on up to 90 ml water, 10 ml alcohol. Draw a graph with the amount of alcohol on the horizontal axis and the total volume on the vertical axis. What combination produces the greatest loss in volume?
3. Draw a graduated cylinder 10 cm × 20 cm on a piece of paper. Arrange, within the drawing, 16 quarters or 23 pennies or nickels or dimes separately and then mixed. Which combination produces the greatest loss of volume after mixing? Does this tell you anything about the mixing of alcohol and water?
4. Try mixing alcohol and water by adding the alcohol first. Can you keep them separated to measure the total volume before mixing? Explain.
5. Do solids have holes in them too? Ask your teacher for some gold foil. Hold it up to the light. What do you conclude? Why can't you see through a piece of aluminum foil?

In 1674, Sir William Petty proposed that the particles of matter are invisible, unchangeable, rotating magnetic spheres. He thought you would need at least a million of them held together by magnetism, to provide a visible particle of matter.

The particles of Niklaas Hartsoeker in 1696 have shapes according to the properties of the substance involved. Iron particles, for example, have tiny teeth which interlock in solid iron, but separate to allow molten iron to flow.

The first scientific school was founded in Greece about 600 BC by Thales, Anaximander and Anaximenes. Thales believed that matter was essentially water in one of its three forms: solid, liquid or gas. Anaximander suggested that some special substance existing in four forms – earth, mist, fire and water – was the source of matter. Anaximenes thought that mist or air was the fundamental substance, transformed by rarefaction and condensation into other forms of matter.

2.14 Review

1. One of the early Greek philosophers, Aristotle, suggested that there were just two kinds of matter, earth-seeking and sky-seeking. Stones and baseballs fall when released, but smoke rises, and clouds float far up in the sky.
   (a) Give other examples of earth-seeking and sky-seeking objects.
   (b) Are sky-seeking objects always sky-seeking, and are earth-seeking objects always earth-seeking? Give examples.
   (c) How would the sun and the moon be classified in this system?
   (d) Is this a good theory? A good theory should explain all available observations, but it should then be able to predict new observations. If you discover some new material or object, does this theory predict what will happen to it when it is released?
2. Some years later, when Sir Isaac Newton was trying to explain the same observations as above, he suggested that each object attracts every other object. Large objects attract

more strongly than small objects. An apple released near the Earth is attracted and pulled down to it. The Moon is kept close to the Earth by the same force of attraction. If the force were stronger, the Moon would be pulled right down to the Earth.

(a) Cavendish tested the theory by placing a small object on the end of a thread near a giant lead sphere about 1 m across. What do you think happened?

(b) A ball thrown up in the air might be considered temporarily sky-seeking. What does our new theory predict will happen to it?

(c) What do you think would happen to smoke or clouds on the moon? Why?

(d) Why do scientists not believe in sky-seeking or earth-seeking objects any more?

Around 1650, René Descartes, a French mathematician, argued that no part of space could be empty; that there must be two kinds of matter, regular and weightless, filling all space; and that matter is continuous.

Sir Isaac Newton (1642-1727) said, "The smallest Particles of Matter may cohere by the strongest Attractions, and compose bigger Particles of weaker Virtue; and many of these may cohere and compose bigger Particles whose virtue is still weaker, and so on for divers Successions, until the Progression ends in the biggest Particles on which the Operations in Chymistry, and the Colours of natural Bodies depend, and which by cohering compose Bodies of a sensible Magnitude."

3. We are trying to convince you that our theory of matter is correct and that matter is made of tiny particles, different ones for different kinds of matter. To prove that we are correct, we are going to have to show that our theory explains the results of each and every experiment that has been done or can be done. To prove us wrong, you only need to find one observation that cannot be explained. The theory must then be changed or dropped. This has happened many times already, and will no doubt happen again. On the other hand, scientists find it difficult to give up good theories: that is, theories which explain many observations. Some theories have remained for hundreds of years, long after they were shown to be faulty. Often this happens because no new theory is suggested to replace the old one, or else people keep hoping someone will discover a loop-hole in the old theory.

   Are there problems with the particle model? What if you were told that when you mix liquids together, sometimes the volume does not change at all? How can you explain this? Or what would you say if you were told that sometimes the volume after mixing is greater? What kind of particles would do that? Try to find answers to these questions.

In 1758, Roger Boscovich advanced the theory – opposed to Newton's theory – that particles repel each other when they meet. They have no size, but exist only as points floating in a vacuum. As the particles move away from one another, they alternately attract and repel one another, eventually attracting one another at great distances.

2.15 Instructional Objectives

1. To describe the continuous and the particulate theories of matter.

2. To give two characteristics of a dispersion.

3. To give two characteristics of a suspension.

4. Given a test tube containing a mixture, to be able to classify it as a solution, dispersion or suspension.

5. Using the particulate theory, to distinguish between solutions, dispersions and suspensions.

6. Using the particulate theory, to explain the change in volume of a solution during dissolving.

2.16 Glossary

Aristotle
continuous theory of matter
Democritus
dispersion
Leucippus
particle
particulate theory of matter
suspension
Thales of Miletus
theory

Crystals

3.1 Substances with Shapes
3.2 What Is a Crystal?
3.3 Investigation: Looking at Crystals
3.4 Making Crystals
3.5 Investigation: Saturated Solutions and Crystal Formation
3.6 Investigation: Crystal Formation from Molten Materials
3.7 Exercise: Using a Theory to Make Predictions
3.8 Investigation: Cutting Crystals
3.9 Investigation: Crystal Sizes
3.10 Investigation: Growing Large, Perfect Crystals
3.11 Particle Similarities and Differences
3.12 Investigation: Particle Similarities
3.13 Investigation: Metallic Crystals
3.14 Summary
3.15 Further Investigations
3.16 Review
3.17 Instructional Objectives
3.18 Glossary

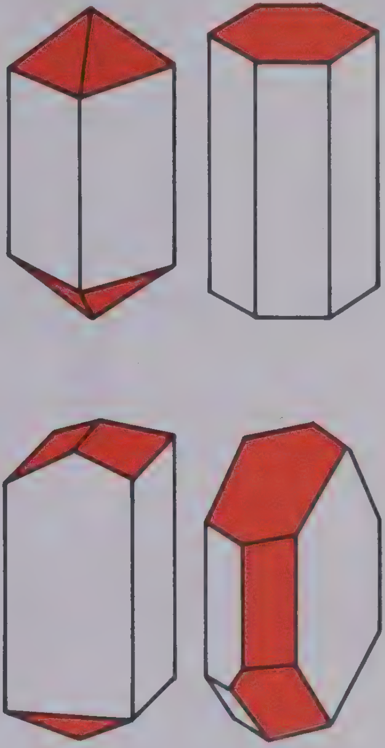
3.1 Substances with Shapes

Of the pure substances used so far in our investigations, there are eight solids and only two liquids. Of the eight solids, only one does not form crystals. Even water crystallizes when it freezes.

1. sugar
2. salt
3. potassium nitrate
4. copper sulphate
5. ammonium chloride
6. sodium sulphate
7. sodium thiosulphate
8. starch
9. water
10. alcohol

Why do crystals turn up so often? What do all these materials have in common that allows them to form crystals? What do our theories have to say about crystals?

The Greek word for frost was *kyros*. They called the patterns produced by snow and ice *krystallos*. Later, when they found transparent pieces of rock with flat sides and equal angles, they named them *krystallos* too.



3.2 What Is a Crystal?

If you look closely at fresh salt crystals, you will see many tiny cubes, all with flat sides, sharp 90° corners and straight edges. A perfect salt crystal is colorless and transparent, like glass, but in a box of salt, the faces and edges become scratched and broken. Light reflected from millions of tiny surfaces makes a spoonful of salt look white. But why cubes? And do other materials form cubes too?

3.3 Investigation: Looking at Crystals

PROBLEM: WHAT CAN WE LEARN ABOUT THE NATURE OF CRYSTALS FROM OBSERVATION?

PROCEDURE:

Examine the crystals your teacher has displayed in the classroom. Use a stereo microscope or other magnifier if necessary. Construct a data table to organize the observations made at each station.

OBSERVATIONS:

1. Material
2. Are all the crystals in the sample the same size?
3. Are all the crystals in the sample the same shape?
4. Sketch the shape that occurs most often.
5. What color are the crystals?
6. Are the crystals transparent (like glass), translucent (like frosted glass) or opaque?
7. Do the crystals have straight edges, equal angles or flat sides?
8. Are these crystals similar to any of the other samples?

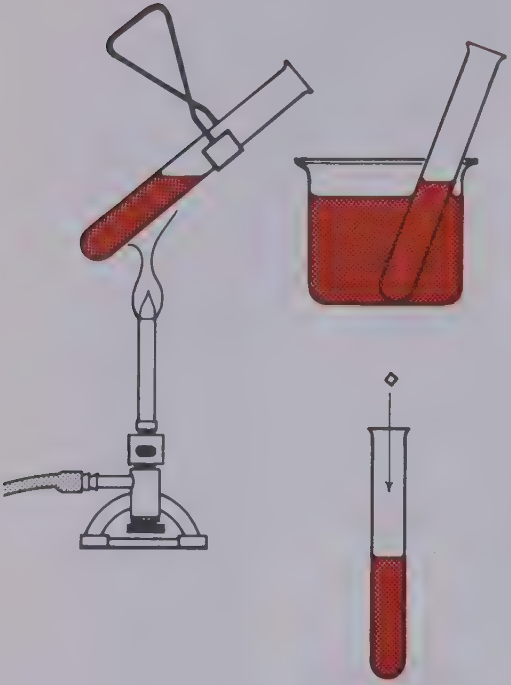
When you finish, put all this knowledge to work. The teacher has a large sample of one of the substances on the front desk. Try to identify it with the information in your data table.

Some crystals you might look at are
- salt
- sugar
- potassium nitrate
- copper sulphate
- ammonium chloride
- sodium sulphate
- sodium thiosulphate
- potassium permanganate
- nickel sulphate
- alum
- chrome alum
- Rochelle salt
- calcite
- mica

3.4 Making Crystals

Crystals form as water evaporates from solutions. Crystals also form as a saturated solution cools. This does not happen with every solution.

Sometimes, when a solution cools, no crystals form at all. The solution is somehow able to hold more dissolved material than would be expected. The material is able to stay in solution without crystallizing. In the next investigation, you are going to examine a supersaturated solution made with hypo crystals.



Make sure that your test tube is extremely clean to start with. A tiny speck of dust can start crystallization before you add your seed crystal.

3.5 Investigation: Saturated Solutions and Crystal Formation

PROBLEM: DO CRYSTALS ALWAYS FORM WHEN A SATURATED SOLUTION COOLS?

MATERIALS:

20 × 150 mm test tube
test tube holder
beaker of cold water
Bunsen burner
sodium thiosulphate

PROCEDURE:

Put two drops of water in the test tube. Fill the test tube half full of hypo crystals (sodium thiosulphate) and dissolve them by heating and shaking. Let the solution cool to room temperature in the beaker of cold water.

You will remember from Investigation 1.13 that this usually starts crystals growing. If all goes well, no crystals will form and the solution will be supersaturated. Now add one more crystal, holding the cool test tube in your hand. Watch and feel what happens. You can heat the crystals to dissolve them again if it doesn't work the first time or if you want to try it again.

QUESTIONS:

1. Sketch the shape of the crystals that form.
2. Was heat taken in or given out by the crystals as they formed?
3. Would continuous matter form crystals?
4. Would matter form crystals if it were particulate?
5. Is this way of growing crystals anything like the formation of ice? Does ice take in or give out heat while freezing ?

3.6 Investigation: Crystal Formation from Molten Materials

PROBLEM: DO MOLTEN MATERIALS ALWAYS FORM CRYSTALS AS THEY SOLIDIFY?

MATERIALS:

microscope slide
magnifier
salol

PROCEDURE:

Heat a small amount of salol on the slide until it melts. Watch it solidify with the magnifier, stereo microscope or projection microscope. If it cools but does not solidify, it is supercooled. Add a small seed crystal of salol to get things started.

QUESTIONS:

1. What shape are the crystals that form?
2. Are all the crystals alike?
3. How can a material know what shape its crystals should be after it has melted or dissolved?
4. Which theory best explains what happens?
5. How does a salt crystal grow? What does the particle theory predict?

This theory raises more questions:

6. Can the particles move? If so, how, and how do they know where to go?
7. Why do the particles stick together when they meet?
8. How does heating the crystal make the particles come apart?

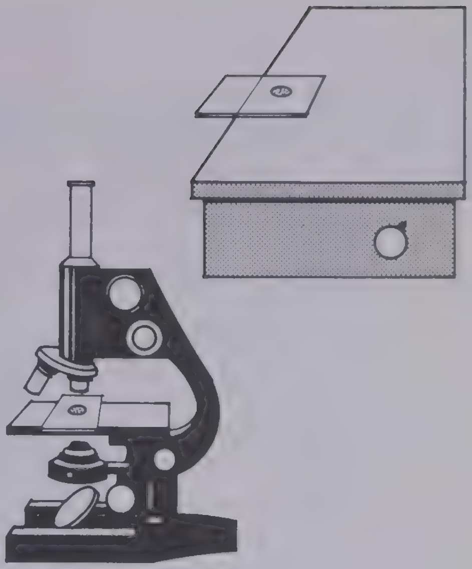
3.7 Exercise: Using a Theory to Make Predictions

The particle theory claims that a saturated solution is crammed full of particles of the dissolved material. As this solution cools, or as the water evaporates, the particles join back together again. If they connect up in neat rows, crystals will be formed.

Let us try to predict how this will happen. Get a dime and draw a round particle. Then draw another similar particle attached to it. Then add another and another until you get a shape that you have seen on the face of a crystal. Try several ways of attaching them to make as many different shapes as possible.

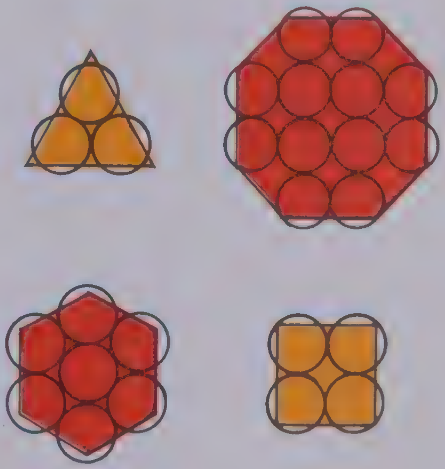
QUESTIONS:

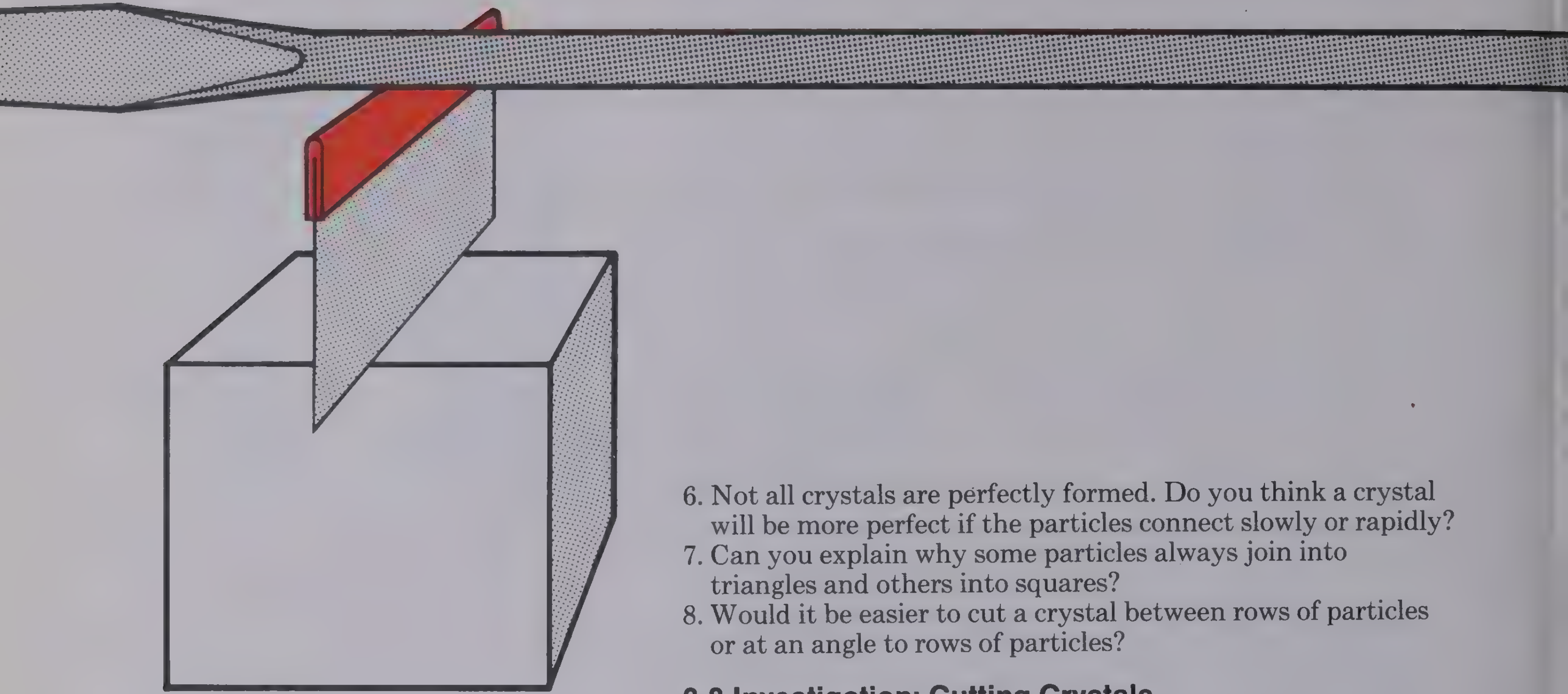
1. In how many regular ways can two particles be joined together? In how many regular ways can four particles be joined together?
2. Which arrangement of particles has the least space between particles? Which has the most?
3. What is the maximum number of particles that another particle can touch?
4. Do the particles have to be round? What other shapes would work? Could a triangular crystal be made with square particles? Draw it.
5. Do all the particles have to be the same size to make a perfect crystal? Explain.



Salol's chemical name is phenyl salicylate. It is used as a preservative in medicines and as a light absorber in plastics, waxes, polishes and suntan oils. It absorbs ultra-violet light, which causes fading, yellowing and cracking.

Three-dimensional marble models can be made from marbles stuck together with drops of wax from a lit candle or from styrofoam balls stuck together with toothpicks.





Even the kind of rock salt used for melting ice on sidewalks is large enough for this investigation.

Can you make a perfect cube from your rock salt crystal? Can you make a triangular crystal with perfectly smooth sides from rock salt?

6. Not all crystals are perfectly formed. Do you think a crystal will be more perfect if the particles connect slowly or rapidly?
7. Can you explain why some particles always join into triangles and others into squares?
8. Would it be easier to cut a crystal between rows of particles or at an angle to rows of particles?

3.8 Investigation: Cutting Crystals

PROBLEM: DO CRYSTALS CUT MORE EASILY IN SOME DIRECTIONS THAN IN OTHERS?

MATERIALS:

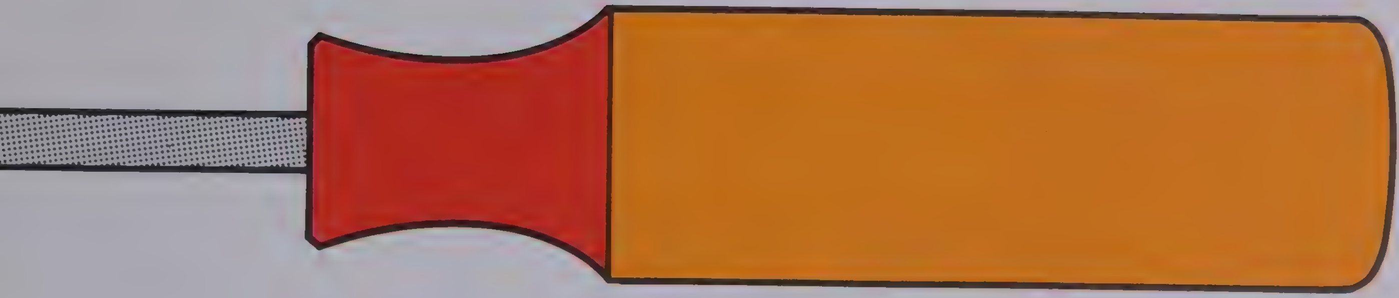
single-edged razor blade
small hammer or screwdriver
large crystals of calcite and rock salt
other crystals such as mica or feldspar

PROCEDURE:

Hold the razor blade parallel to one of the edges of the crystal and tap it firmly with a small hammer or screwdriver. Try cleaving (splitting) the crystal along lines parallel to other edges and at other angles.

QUESTIONS:

1. Which theory of matter best explains how crystals are cut?
2. According to the theory, should a small crystal cleave in the same way as a large crystal? Explain.
3. Are there arrangements of particles in crystals which might not have cleavage planes? Draw some if you can.
4. Which directions should cleave most easily?
5. What kind of particle arrangements would you find in a calcite crystal?



3.9 Investigation: Crystal Sizes

PROBLEM: CAN THE SIZE OF CRYSTALS FORMED BY EVAPORATION BE CONTROLLED?

MATERIALS:

dropper bottle filled with sulphur dissolved in carbon disulphide
2 watch glasses
funnel

PROCEDURE:

Sulphur is a solid yellow substance which, strangely, does not dissolve in water. It will dissolve in carbon disulphide, a pungent, explosive liquid. Put a drop of this solution on each of the watch glasses and cover one with the funnel. Inspect the residue with a stereo microscope or other magnifier.

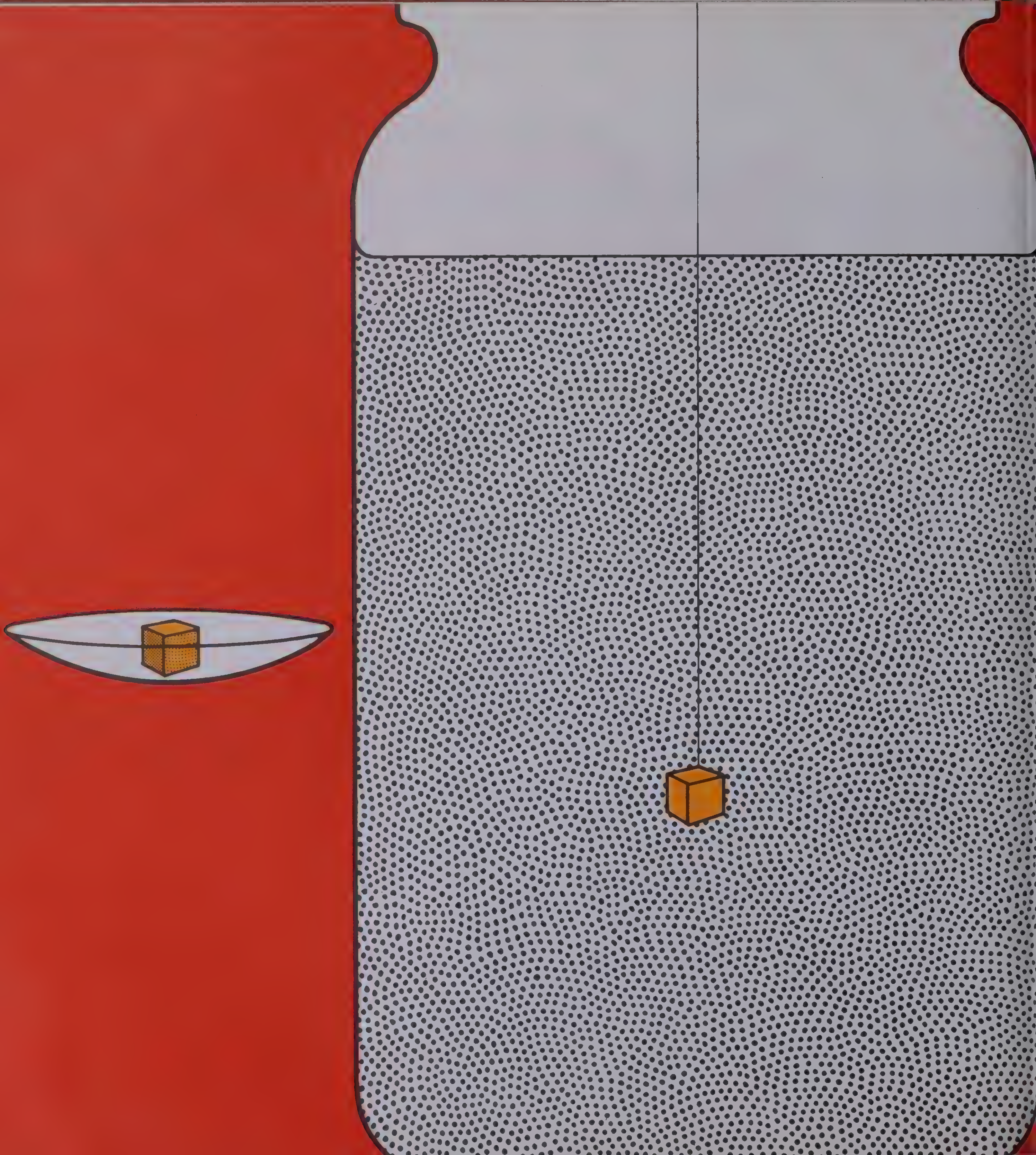
QUESTIONS:

1. What effect does the funnel have on the rate of evaporation?
2. What effect does the funnel have on the rate of crystal formation?
3. What effect does the rate of formation have on the size of the crystals?
4. What shape are the crystals that form? Sketch them.
5. Can you show how particles might join together to form these crystals?
6. Which theory best explains why some crystals are larger than others? How?

After smelling carbon disulphide, perhaps you can understand why it is sometimes used as a rodenticide. Be careful how you handle it.

Sulphur is a useful substance found in huge deposits in Texas, Louisiana and Mexico. Superheated water is pumped down to melt the sulphur, which is then pumped out of the ground and allowed to harden. In Canada, thousands of tonnes of sulphur are removed daily from "sour" natural gas before shipment. The sulphur is used to make sulphuric acid, one of the most valuable industrial chemicals, which is used in the vulcanization of rubber, in drugs, insecticides, explosives, fertilizer, dyes and in the pulp and paper industry. In Canada, we use about 1 000 000 t of sulphuric acid a year.

These crystals have a special shape, called rhombic.



3.10 Investigation: Growing Large, Perfect Crystals

PROBLEM: HOW DO YOU GROW LARGE, PERFECT CRYSTALS?

In the previous investigations, you found out that crystals are larger when formed slowly. This eliminates two of the following methods of growing crystals. Which two?

1. cooling a saturated solution
2. evaporating a saturated solution
3. seeding a supersaturated solution
4. seeding a supercooled liquid

To decide which of the two to use, consider how to control either the rate of cooling or the rate of evaporation to grow the crystals as slowly as possible. Which is simpler, to cool a solution slowly over a period of weeks or to allow it to evaporate slowly? Evaporation is the only answer. Why?

MATERIALS:

30 g of alum
250 ml beaker
watch glass
large jar
fine wire,
thread or hair
funnel
filter paper

Alum is used in water purification. When added to water, it forms a jelly-like substance which falls to the bottom of the container, carrying with it any suspended bits of matter.

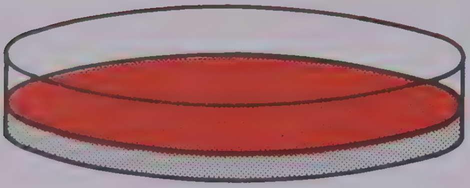
PROCEDURE:

Dissolve 30 g of alum in 200 ml of water by heating and stirring. Pour some of the solution into a watch glass. Put the rest of the solution into a large jar and put both the jar and the watch glass away to cool overnight. The next day, pick the best seed crystal from the watch glass, tie it to the end of a fine wire, thread or hair and suspend it in the saturated alum solution. Keep any extra solution in another jar.

To be sure of getting large crystals:

1. See that glassware is absolutely clean. Small crystals start growing on dirt and dust specks.
2. Filter the saturated solution into its container to remove any undissolved crystals or foreign particles.
3. Cover the container, except for a small opening. The size of the opening controls the rate of growth.
4. Add saturated solution to keep the solution volume fairly constant. Adding water alone will dissolve the crystal.
5. Remove any crystals growing on the thread or on the bottom of the container. The particles then attach themselves to the main crystal.
6. Keep it at home in a cupboard where the temperature is constant.
7. Don't handle the crystal after it has grown. It will dissolve in the moisture on your hands. Keep it in a sealed container, such as a plastic pill bottle.

While your crystal is growing, watch how its shape changes. Is the large crystal just a larger version of the small crystal? What happens to bumps and holes on the seed crystal? What happens around the suspending wire? Do the flat sides get flatter or more uneven? Try to explain your observations in terms of the particle model



3.11 Particle Similarities and Differences

A copper sulphate crystal will grow in a copper sulphate solution. A hypo crystal will grow in a hypo solution. What would happen if a copper sulphate crystal were placed in a hypo solution? Would a crystal grow? What can our theory tell us? Both these materials are supposed to be made of particles. Maybe the particles of one are similar to the particles of the other. Perhaps hypo particles can join the copper sulphate crystal to build a bigger crystal. On the other hand, what if the particles are quite different? Perhaps hypo particles are much bigger, or the wrong shape to fit in the copper sulphate crystal. They may be triangles trying to hook onto squares. If they are too different, perhaps no crystal can grow. In the next investigation, we take this one step further. Suppose we make a solution of three substances, all mixed together, and evaporate the water from it. What will happen? Will three separate kinds of crystals grow? Or one kind of crystal? How alike are the particles of these three materials?

Silver nitrate is used to make the light-sensitive emulsion on photographic films, both color and black and white. The photographic industry is the largest single user of silver.

The alchemists named silver nitrate "lunar caustic", and copper sulphate, "blue vitriol".

3.12 Investigation: Particle Similarities

PROBLEM:ARE THE PARTICLES OF DIFFERENT MATERIALS SIMILAR?

MATERIALS:

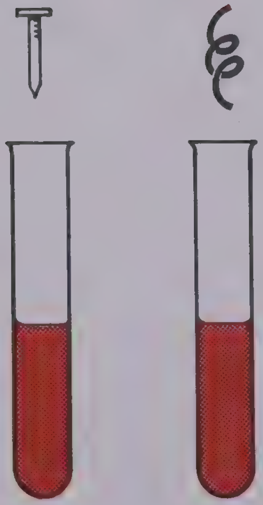
20 × 150 mm test tube
petrie dish
Bunsen burner
copper sulphate
alum
chrome alum

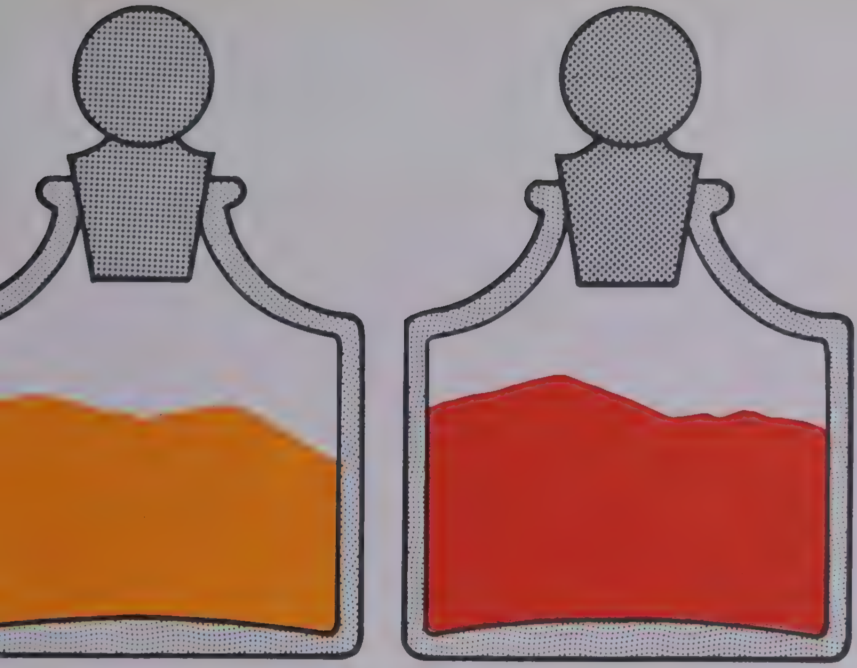
PROCEDURE:

Measure out 4 g of copper sulphate, 2 g of alum (potassium aluminum sulphate), and 2 g of chrome alum (potassium chromium sulphate) into the test tube. Dissolve in water, heating if necessary. Pour the solution into the petrie dish and allow it to cool and evaporate.

QUESTIONS:

1. If the three types of particles are all different, how many kinds of crystals should grow?
2. If the three kinds of particles are all quite similar, how many types of crystals should grow?
3. How many kinds of crystals did grow?
4. Are all the particles alike?
5. Are all the particles completely different?





3.13 Investigation: Metallic Crystals

PROBLEM: DO METALS FORM CRYSTALS?

MATERIALS:

2-13 × 100 mm test tubes
test tube rack
copper sulphate
silver nitrate
iron nail
copper wire
magnifier or
stereo microscope

PROCEDURE:

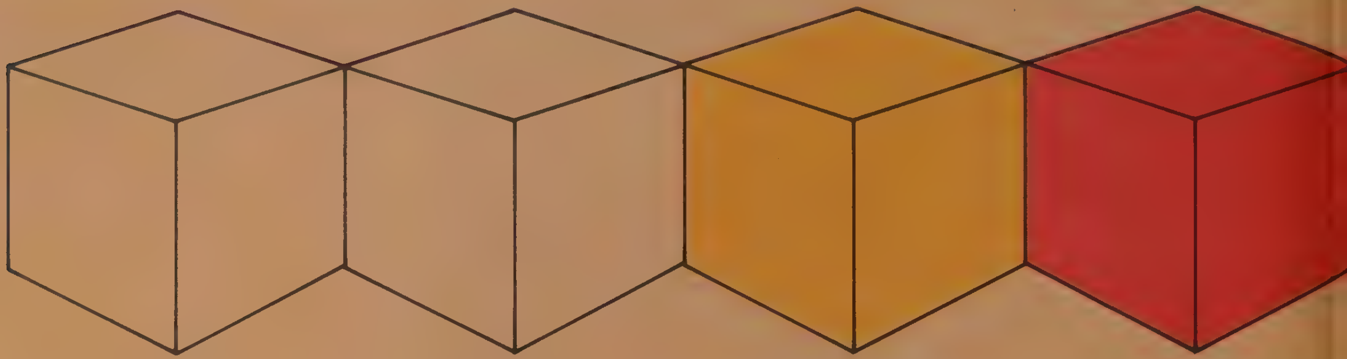
Dissolve a few crystals of copper sulphate in one of the test tubes and one crystal of silver nitrate in the other. Use half a test tube of water in each. Drop the nail into the copper sulphate solution and the copper wire into the silver nitrate solution. Examine the products.

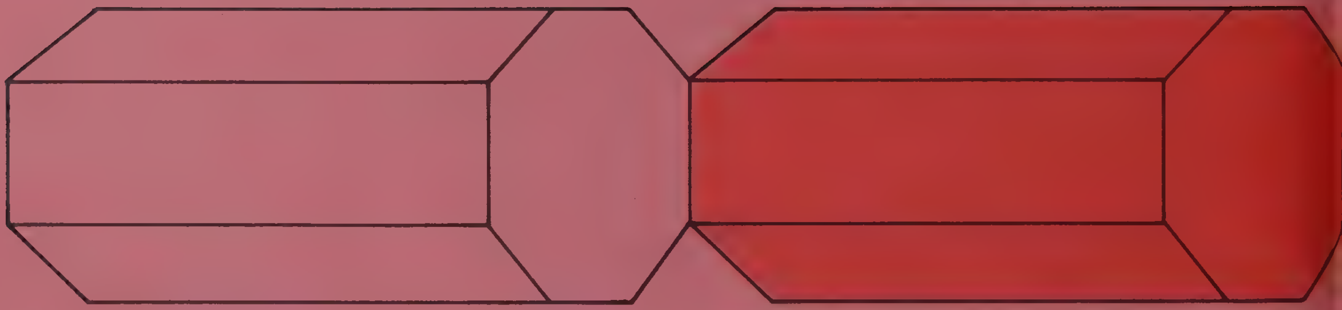
OBSERVATIONS:

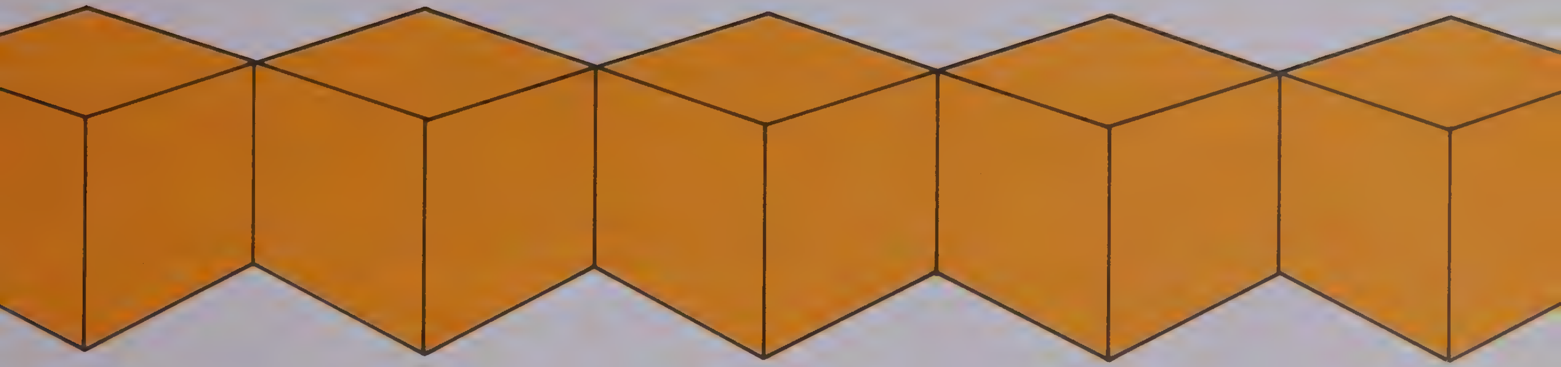
For both samples—the nail in copper sulphate and the wire in silver nitrate—be sure to note the color of the solution before the object is added; the color of the solution after the object is added and the reaction is over; the color of the deposit; the shape of the crystals formed (if there are any); the identity of the deposit.

QUESTIONS:

1. What do you think happened to the copper sulphate solution? Could you name the substance in solution now?
2. What happened to the silver nitrate solution? Could you name the substance in solution now?
3. Where do the deposits come from?
4. Does the same thing happen if you heat the solutions as the reaction is going on?

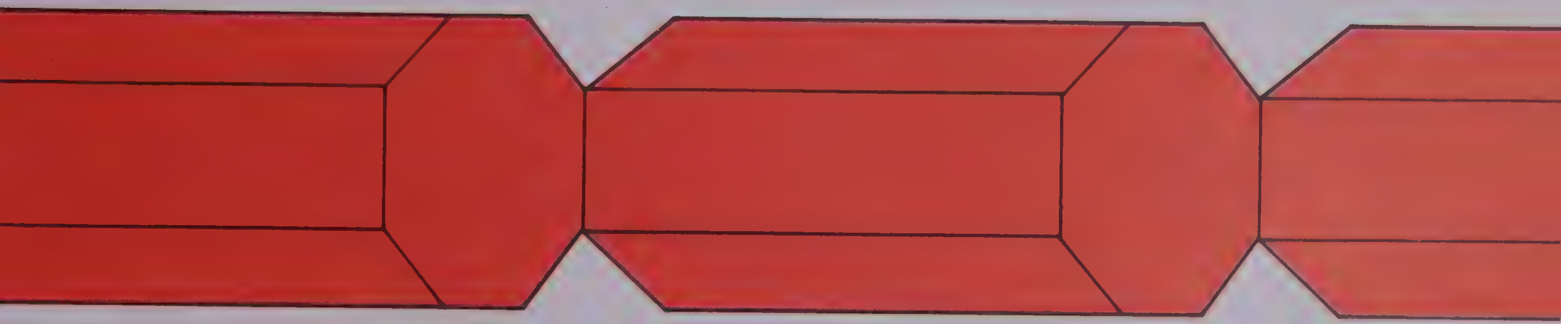


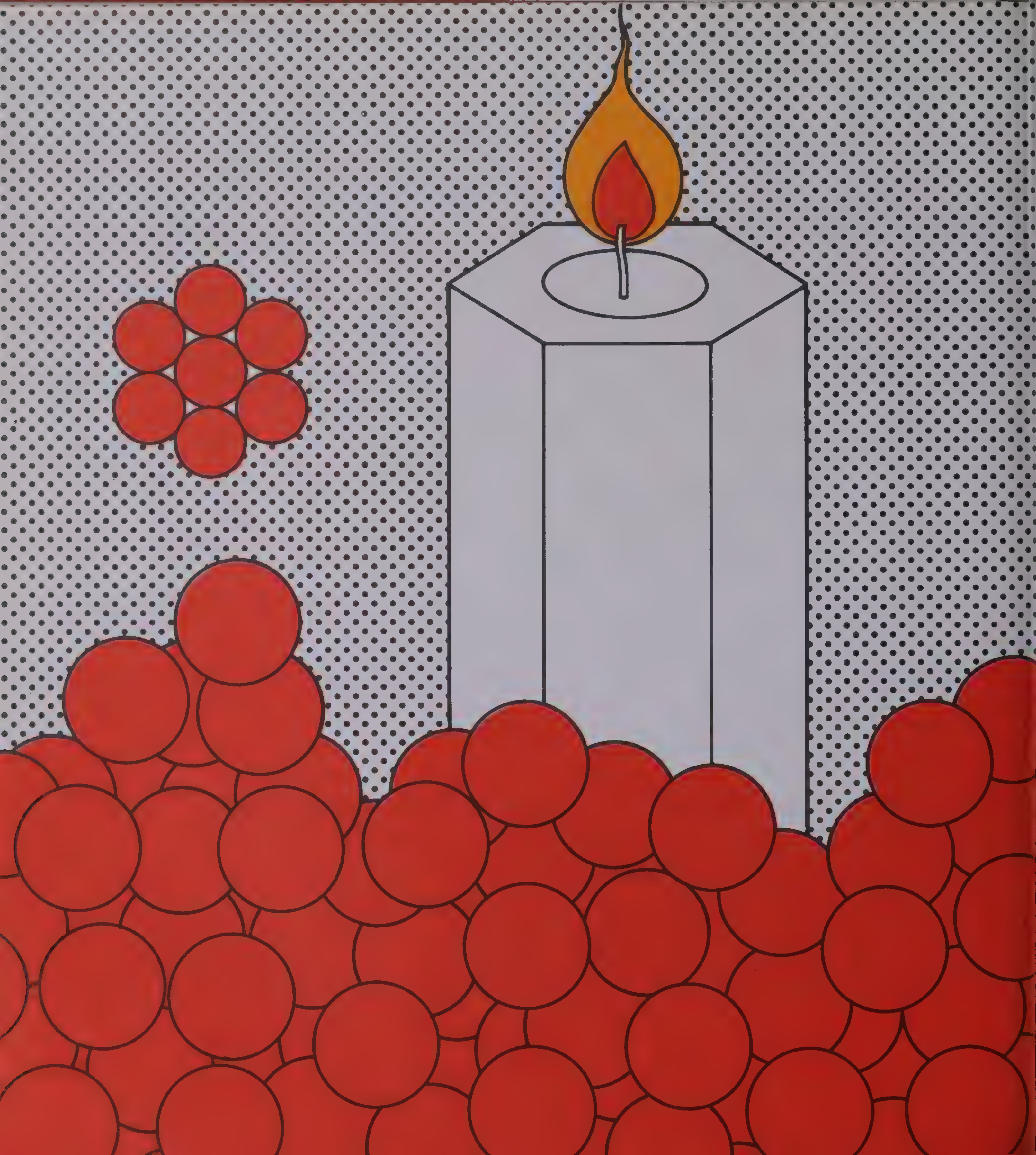




3.14 Summary

1. A crystal is a naturally occurring form of a substance with flat sides, straight edges and equal angles.
2. Crystals can form as a solution evaporates, when a supersaturated solution is seeded or when a substance cools and solidifies.
3. The particle theory suggests that crystals are formed when the particles of a substance join together in a regular pattern.
4. If there are rows of particles, the crystal should cut more easily along these rows.
5. Large crystals are grown very slowly, by slowing the rate of evaporation, slowing the rate of cooling or by slowing the rate of reaction.





3.15 Further Investigations

1. Watch salol grow with a microprojector.
2. Make crystal models with marbles instead of circles. Glue the marbles together with drops of wax from a lighted candle. Crystal models have also been made from styrofoam spheres attached to each other with toothpicks.
3. Put a marble model in a large beaker of water and heat it. Is this what happens during dissolving?
4. Draw diagrams of all the regular figures with three sides up to eight sides, starting with the triangle. Can you duplicate all these shapes with penny particles? Which ones show up as faces on crystals?
5. Grow crystals of other materials such as Rochelle salt, nickel sulphate or chrome alum.
6. Put a drop of silver nitrate solution on a watch glass. Watch silver crystals grow on a copper wire under the microscope.

3.16 Review

CONCLUSIONS FROM THE PARTICLE THEORY:

Let us suppose that crystals of a material like copper sulphate are built of tiny particles lined up in neat rows. What do our experiments tell us about these particles? For each of the following statements about particles, decide if it is true or false, then explain which experiment and which observations demonstrate your answer.

1. All the particles of a material are the same color.
2. All the particles of a material must be very small.
3. When cooled or brought closer together, the particles can hook on to one another in rows, forming a pattern.
4. When heated or shaken, the particles can break away from each other.
5. All the particles of a material are the same size.
6. All the particles of a material are the same shape.
7. Different materials sometimes have quite different particles and sometimes quite similar particles.
8. The particles of some materials are combinations of the particles of other substances.

SAMPLE ANSWER:

1. All the particles of a material are the same color.
   ANSWER: TRUE–In the crystal exercise, each sample had a single color. Each crystal in the sample had the same color throughout. The particles making up these crystals must also be that same color.

Synthetic diamonds were first made in Sweden in 1953. In the first attempts, graphite was heated to a temperature of 2000°C in a 1000 t press. The origin of the carbon does not seem to matter: diamonds have been successfully produced from peanut butter! Synthetic diamonds are not large, and may never compete with natural diamonds in jewellery stores, but they are ideal for industrial uses – in diamond drill bits, diamond saws for cutting stone and diamond tools for shaping contact lenses.

Photographic film was invented by George Eastman, the founder of the Kodak company. He coated a transparent plastic film with a thin layer of light-sensitive emulsion. This emulsion is a suspension of silver bromide crystals in gelatin. The silver bromide is made by mixing silver nitrate and potassium bromide at the proper temperature to control the size of the crystals produced. Large crystals produce more sensitive emulsions. The crystals are mixed with gelatin and then the transparent plastic film is coated with the mixture. The gelatin is made from cowhide. Certain sensitizing compounds originate in the seeds of the black mustard, and in other plants which cows eat. These compounds help to make the film even more sensitive to light.

Emeralds, rubies and sapphires are all hexagonal crystals. Emeralds are forms of a green mineral called beryl. Rubies and sapphires are both forms of aluminum oxide, a colorless material. Chromium oxide and iron oxide color rubies red, while traces of titanium oxide make sapphires blue.

Large, perfect ruby and sapphire crystals can be grown from the molten substance with a seed crystal. As the crystal forms around the seed crystal, it is slowly raised out of the furnace. In this way a single crystal of 10 cm or more can be grown. Synthetic ruby crystals were used in one of the first kinds of lasers. Natural rubies are neither large enough nor perfect enough to work properly.

Transistors are specially grown silicon and germanium crystals. A pocket radio may contain a dozen, a pocket calculator as many as 50 000, all on a chip no bigger than a thumbnail

PROBLEMS WITH THE CONTINUOUS THEORY:
Can the continuous theory explain all the things that the particle theory explains? If we are to keep the continuous theory, we must find explanations somewhere. Try to explain each of the observations below. If you can't, the continuous theory is in real trouble.

1. When a crystal dissolves, its shape naturally disappears. How can crystals form in the same shape again if the solution is cooled or evaporated?
2. How can crystals form at all? (If someone asked you to make a large cube, it would be easy to build one from sugar cubes, but much more difficult with a lump of clay that would have to be shaped by hand.)
3. How can different crystals form from a solution of two or three different materials? Why isn't there just one kind of crystal formed?

PROBLEMS WITH THE PARTICLE THEORY:

1. According to the particle theory, as a salt crystal dissolves, its particles break away and mix with the water particles. Why does the solution become saturated?
2. Why do most crystals absorb heat as they dissolve and give out heat as they form?
3. Why does more material dissolve at a higher temperature?

If you can't explain any of these problems, then the particle theory is in trouble too.

3.17 Instructional Objectives

1. To identify four properties of crystals which make them crystals.

2. To describe four methods by which crystals form.

3. To describe, using a simple particle theory, what a crystal is and how it forms.

4. To describe, using a simple particle model, why crystals can usually be cut more easily in some directions than in others.

5. To describe how to grow large, perfect crystals and explain why these methods work, using a simple particle model.

3.18 Glossary

crystallize
cleavage
deposit
molten
opaque
solidify
supercool
supersaturated solution
translucent
transparent

Density

4.1 What is Density?
4.2 Investigation: Size / Density
4.3 Density and the Particle Theory
4.4 Which Arrangement is the Most Dense?
4.5 Solids, Liquids and Density
4.6 Investigation: Density / Buoyancy
4.7 Investigation: Buoyancy in Various Liquids
4.8 Challenge: Who Can Float the Biggest Boat?
4.9 Exercise: Making Monoclinic Sulphur
4.10 Exercise: Making Amorphous Sulphur
4.11 Exercise: Why Three Kinds of Sulphur?
4.12 Exercise: The Densities of the Forms of Sulphur
4.13 Another Kind of Matter
4.14 Investigation: Gases / Mass, Volume and Density
4.15 Summary
4.16 Further Investigations
4.17 Review
4.18 Instructional Objectives
4.19 Glossary

4.1 What Is Density?

Our particle theory says that matter is built from particles packed together in different ways. In some arrangements, the particles are close together. In other arrangements the particles are grouped further apart, increasing the amount of space between them.

The same number of particles may take up different volumes, depending on how they are packed. This might explain why a block of iron is heavier than a block of aluminum the same size. Perhaps the particles are packed more closely in the iron.

Density measures the degree of particle packing in a material. Density is measured in kilograms per cubic metre or, sometimes, in grams per millilitre.

The density of any size block of matter can be calculated by dividing its mass by its volume.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$D = \frac{M}{V}$$

example: $$D = \frac{250\ \text{kg}}{8\ \text{m}^3} = 31.25\ \text{kg/m}^3$$

What we are really doing is finding out the mass of 1 m^3 of the substance.

Imagine a row of blocks, each of a different material, but all measuring 1 m by 1 m by 1 m. The heaviest will be the most dense and the lightest will be the least dense. A block with a mass of 250 kg would have a density of 250 kg/m^3.

Underneath this row, there is one more block, but it is 2 m by 2 m by 2 m. It has a mass of 500 kg. Is it as dense as the previous block? Is it made of the same material as that block? Are its particles packed as closely together?

Did you say it was the same density? It has twice the mass, but did you notice that it does not have twice the volume? Its volume is $2\ \text{m} \times 2\ \text{m} \times 2\ \text{m} = 8\ \text{m}^3$.

If you sawed this block into cubes 1 m on each side, you would end up with eight of them. Each would have a mass of $\frac{500\ \text{kg}}{8}$ or 62.5 kg. This block has a density of 62.5 kg/m^3. It is far less dense than the first block.

Density can also be measured in grams per millilitre. Here we are comparing the mass of 1 ml of each substance.

Three hundred millilitres of alcohol would have a mass of 240 g. Two hundred millilitres of sulphuric acid might have a

The volume of a rectangular block is calculated by multiplying its length times its width times its height.

$V = l \times w \times h$

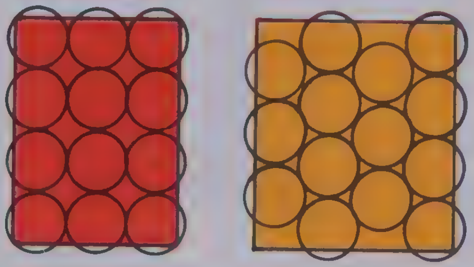
The volume of a sphere is calculated by multiplying its radius cubed by $\frac{4}{3}\pi$

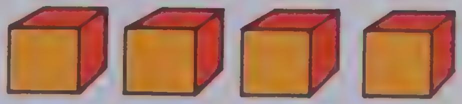
$V = \frac{4}{3}\pi r^3$

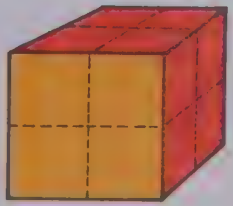
You should know by now that the greek letter π (pi) stands for the number 3.14159265358979323 84, and so on, which we will round off to 3.14 for any problems in this course.

1.2 g/ml would be the same as 1200 kg/m^3.

5480 kg/m^3 is the same as 5.48 g/ml.



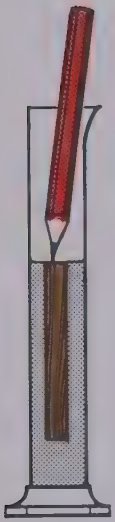




mass of 360 g. Their densities are calculated as follows:

$$\text{density of alcohol} = \frac{240\text{ g}}{300\text{ ml}}$$
$$= 0.8\text{ g/ml}$$

$$\text{density of acid} = \frac{360\text{ g}}{200\text{ ml}}$$
$$= 1.8\text{ g/ml}$$



More matter is packed into each millilitre of sulphuric acid than into a millilitre of alcohol.

COMPARING DENSITY UNITS

An object with a density of 1 g/mm^3 would be quite dense. It would take 1000 mm^3 to make 1 ml, that would have a mass of 1000 g or 1 kg.

1 g/mm^3 = 1000 g/ml

An object with a density of 1 g/ml is not quite as dense. It takes 1000 ml to make a litre, which would then have a mass of 1000 g or 1 kg.

1 g/ml = 1 kg/ℓ

It takes 1000 ℓ to make a cubic metre, which, at this rate, would have a mass of 1000 kg.

1 g/ml = 1000 kg/m^3

According to the particle theory, an object twice as big, of the same material, should contain twice as many particles – that is, it should have twice the mass. However, the larger object would still have the same mass per cubic metre, in other words, the same density. Investigation 4.2 tests this prediction. Do big wooden dowels have the same density as small wooden dowels?

4.2 Investigation: Size / Density

PROBLEM: DOES DENSITY DEPEND ON THE SIZE OF THE OBJECT?

MATERIALS:

several 2 cm diameter round wooden dowels of various lengths
equal-arm balance
100 ml graduated cylinder

These dowels will have to be waterproofed to keep them from absorbing water and increasing in mass. You may paint them, varnish them or perhaps even dip them in molten wax.

PROCEDURE:

Determine the mass of each of the dowels very carefully. Measure the volume of each dowel by dropping it into a graduated cylinder half full of water. The volume of the dowel will be the amount the water rises. Be sure to measure the total volume by poking the dowel just under the surface of the water with the point of a pencil.

How far do dowels sink before they begin floating? Do they all sink until the same amount is under water, or until the same amount is above water, or until the same fraction is under water, or what?

Calculate the density of each dowel by dividing its mass in grams by its volume in millilitres. The units of density will be grams per millilitre or g/ml.

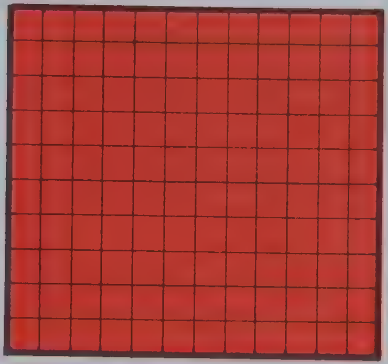
Draw a graph of your results with the volume on the horizontal axis and mass on the verticle axis. Join the points with a smooth line.

OBSERVATIONS:

For each of the five samples, be sure to include mass, volume and density.

QUESTIONS:

1. Allowing for some small experimental errors, do all your dowels appear to have the same density?
2. What was the average density of your dowels?
3. Did your graph pass through point 0,0? Should it?
4. If your samples all had the same density, what shape should your graph be? Was it?
5. Sketch the graph which would result if the density slowly increased as the size of the sample increased.
6. Sketch the graph which would result if the density slowly decreased as the size of the sample increased.
7. Sketch the graph which would result if all the samples were made of iron.



4.3 Density and the Particle Theory

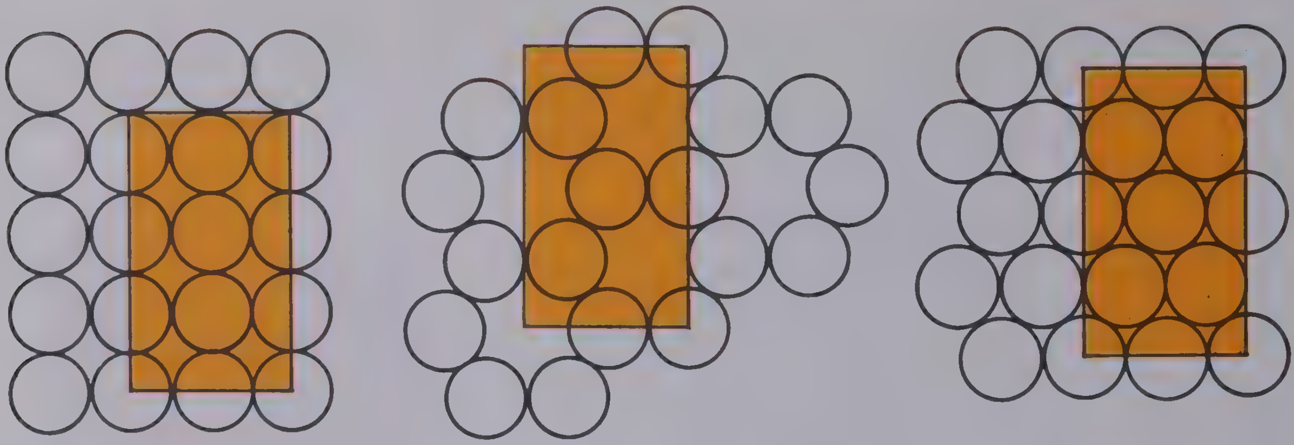
If the particle theory is correct, there are several reasons why the densities of two materials might be different. The second material could have:

1. heavier particles ✓
2. larger particles
3. more space between particles
4. smaller particles ✓
5. lighter particles
6. less space between particles ✓

Which of the above would make the second material more dense? Which would make the second material less dense? Can you suggest two of these reasons which together would produce an object of the same density?

Three of these increase the density of the object and three of them decrease it. Which are which?

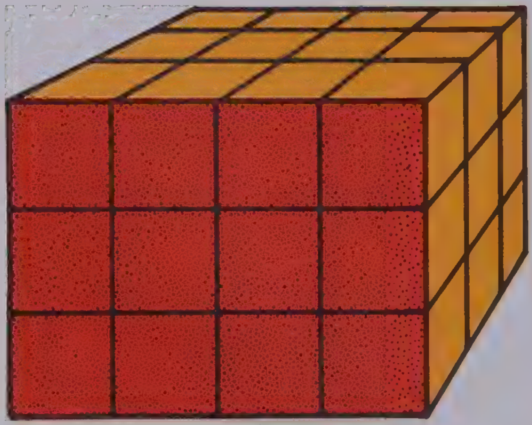
If the particles of two materials are different shapes, could this make a difference in density? Could it ever happen that it would make no difference in density?

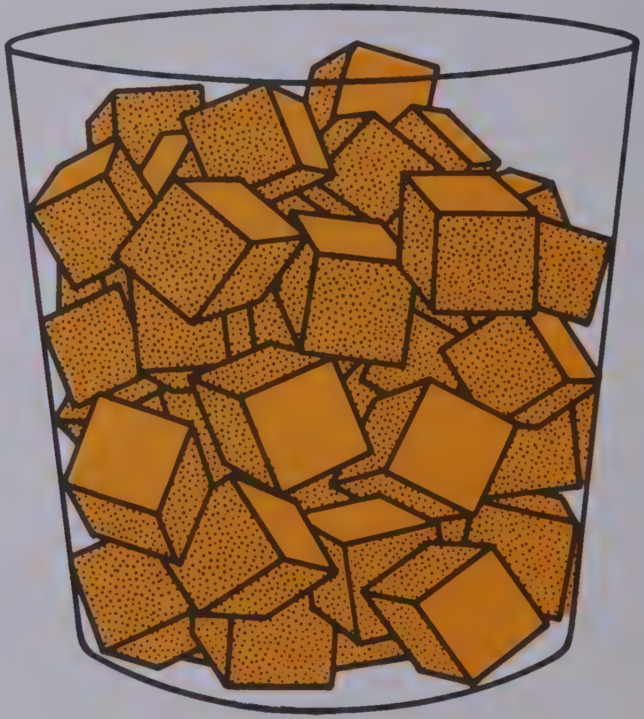


4.4 Which Arrangement is the Most Dense?

Notice that the spaces between particles are larger in some arrangements.

All the rectangles are the same size. Count the number of particles in each. Don't forget to include halves and quarters of circles.





4.5 Solids, Liquids and Density

In a crystal, all the particles are lined up in neat rows. In a liquid, the particles are not attached to each other. How will this particle arrangement affect the liquid's density?

The illustrations show a pile of sugar cubes that have been poured into a plastic container and jumbled. Do they take up the same space as before? Which state of matter should then ordinarily be the most dense? Could a solid ever be less dense than a liquid?

You know what happens when you dig a hole in the ground and then try to fill it up again. The same thing is happening here.

4.6 Investigation: Density / Buoyancy

PROBLEM: DOES DENSITY DETERMINE WHETHER AN OBJECT WILL SINK OR FLOAT?

In this investigation, you will examine various solids and determine their densities. Be sure to compare the results with the density of water.

The problem of floating objects was investigated by Archimedes. He discovered the answer. Can you?

MATERIALS:

various objects
250 ml beaker of water
100 ml graduated cylinder
equal-arm balance

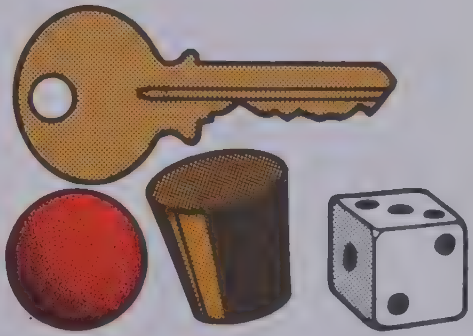
PROCEDURE:

Determine the density of each object. Then test it to see if it floats in water. The mass of each object is easy to find with a balance. The volume of an irregular object can be found using a graduated cylinder. Fill the cylinder with some water, and measure its exact volume. Drop in the object and measure the new volume of water. By subtraction, the volume of the object may be found.

You should know that the density of water is 1 g/ml or 1000 kg/m^3.

OBSERVATIONS:

For each object note mass, volume, density and buoyancy.



QUESTIONS:

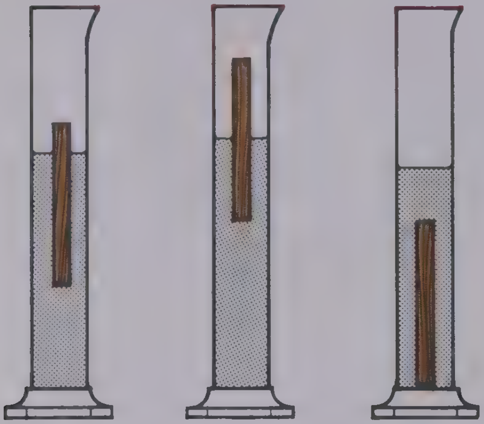
1. How do you tell if an object will float in water?
2. What is the density of water?
3. Is ice more dense or less dense than water?
4. Is a boat more or less dense than water?
5. Is a helium balloon more or less dense than air?

4.7 Investigation: Buoyancy in Various Liquids

PROBLEM: DOES A FLOATING OBJECT SINK THE SAME AMOUNT IN ANY LIQUID?

When an object is lowered into a beaker of water, it pushes the water to one side and makes a kind of hole in the water. The water pushes inwards and upwards and tries to push the object up out of the water. If the object is less dense than water, it is pushed part way out of the water and it floats. If the object is more dense than the water, the object sinks to the bottom. What should happen to the same object in different liquids? Will a dense liquid push with the same buoyant force as a less dense liquid? In this investigation you can find out.

The weighted stick might be replaced by a weighted, stoppered test tube. A scale on a piece of paper could be inserted in the test tube to make measurement easier.



Remember to subtract the mass of the cylinder to find the mass of the liquid alone.

MATERIALS:

100 ml graduated cylinder	weighted wooden stick
equal-arm balance	water, oil, antifreeze, ditto fluid

PROCEDURE:

Find the densities of the liquids. Find the mass of the empty graduated cylinder, then find its mass when it is filled with 100 ml of each liquid. Calculate the mass of 100 ml of liquid and then calculate the density of each liquid.

Measure the depth to which the stick sinks in each liquid. Draw a graph with the density of the liquid on the horizontal axis and the depth to which the stick sinks on the vertical axis.

OBSERVATIONS:

For each sample liquid be sure to note the volume of the liquid, the mass of the cylinder and liquid, the mass of the liquid, the density of the liquid and the depth to which the stick sank.

QUESTIONS:

1. Which is more dense, water or wood?
2. Which liquid was the least dense and which was the most dense?
3. In which liquid did the stick sink the most and in which did it sink the least?
4. Can you see how to use the graph to find the density of some other liquid?
5. What is special about the density of water?
6. If the stick were to sink in a liquid, what does that tell you about the density of that liquid?

4.8 Challenge: Who Can Float the Biggest Boat?

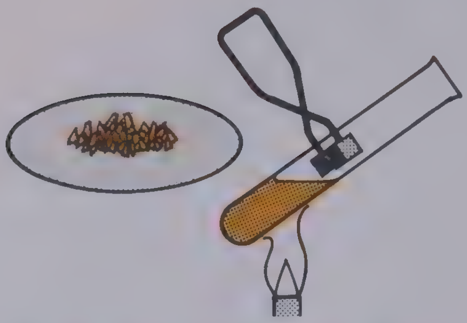
Each person is given a piece of aluminum foil 10 cm by 10 cm. Each must make a boat from the foil to hold as many washers as possible without sinking. Whoever makes the boat which holds the most washers wins a prize.

RULES:

1. Boat must be made from aluminum foil 10 cm by 10 cm.
2. Cutting and taping with masking tape allowed, but any chopped-off pieces of foil have to be carried in the boat.
3. Each person must calculate the volume of his boat correctly before being allowed to test its floating ability.
4. Washers to be added by the owner of the boat one by one until the boat sinks.

QUESTIONS:

1. What can you say about the density of any boat that is still floating?
2. Can you tell who is going to win before the test?



How many sides do these crystals have? Are they transparent? What happens to them after a day or so?

Sulphur melts at 114°C, then becomes gummy and almost black at about 230°C. It finally boils at 445°C. Be careful, this stuff is *hot*!

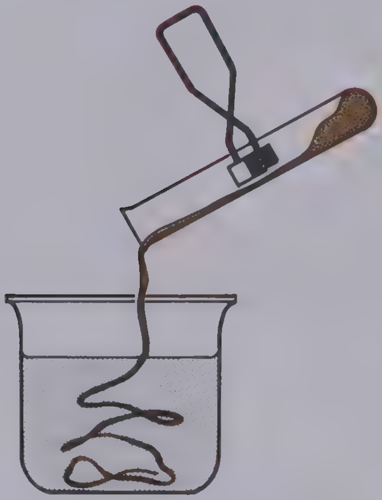
4.9 Exercise: Making Monoclinic Sulphur

In Investigation 3.9, you grew one kind of sulphur crystals, the kind we call rhombic crystals. It turns out that there are at least two other ways to make solid sulphur. Both are produced by cooling molten sulphur.

Heat some roll sulphur gently in a test tube until it melts to a light yellow liquid. Immediately pour it into a filter paper in a funnel. Watch the surface of the molten sulphur and, as soon as the top hardens, remove the filter paper and open it flat. This should produce many tiny yellow crystals. Look at them with a stereo microscope and sketch their shape.

4.10 Exercise: Making Amorphous Sulphur

Melt more roll sulphur but this time keep heating it until it turns dark brown and gummy. Keep on heating and it will again flow easily. Then pour it quickly into a beaker of cold water. This should produce long strands of rubbery sulphur. CAUTION: Sulphur burns with a blue flame producing a dangerous gas. If you set your sulphur on fire, put it out with water or wet paper towels.



4.11 Exercise: Why Three Kinds of Sulphur?

There are two kinds of sulphur that have definite crystal shapes and one kind that has no particular shape. How can this happen? What do our theories have to say this time? The continuous theory is in difficulty explaining why crystals form at all, much less two different kinds. The particle theory will suggest some answers. The sulphur particles could possibly hook on to each other in different ways. What could this mean? How could this theory be checked? What do you think?

1. If the particles connect themselves together in different ways to make different shapes, would there be the same amount of space between particles in the different forms?
2. Should the three forms of sulphur all have the same density?
3. The triangle is the most compact arrangement of particles. Which form of sulphur do you think will turn out to be the most dense?
4. Amorphous sulphur has no particular shape. Are its particles all lined up or jumbled? What does this do to its density?
5. List your prediction for the densities of the forms of sulphur, from least dense to most dense.
6. What kind of investigation should we organize to test our theory?

4.12 Exercise: The Densities of the Forms of Sulphur

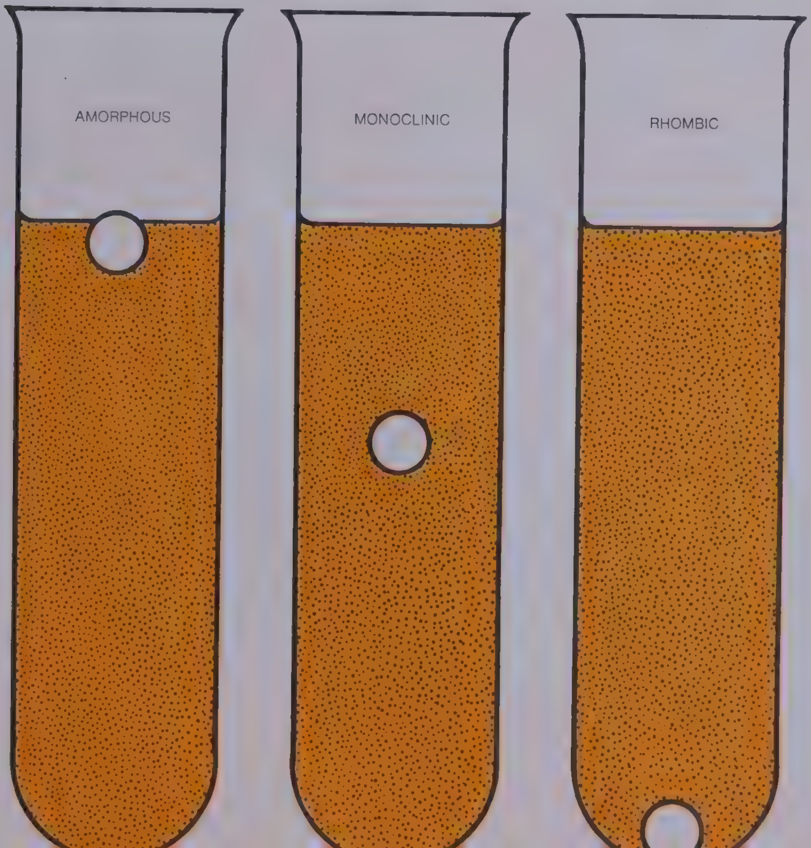
The densities of the three forms of sulphur are very nearly the same. If you try to measure masses and volumes in the usual way, you will find that any tiny experimental error will throw your results out too much.

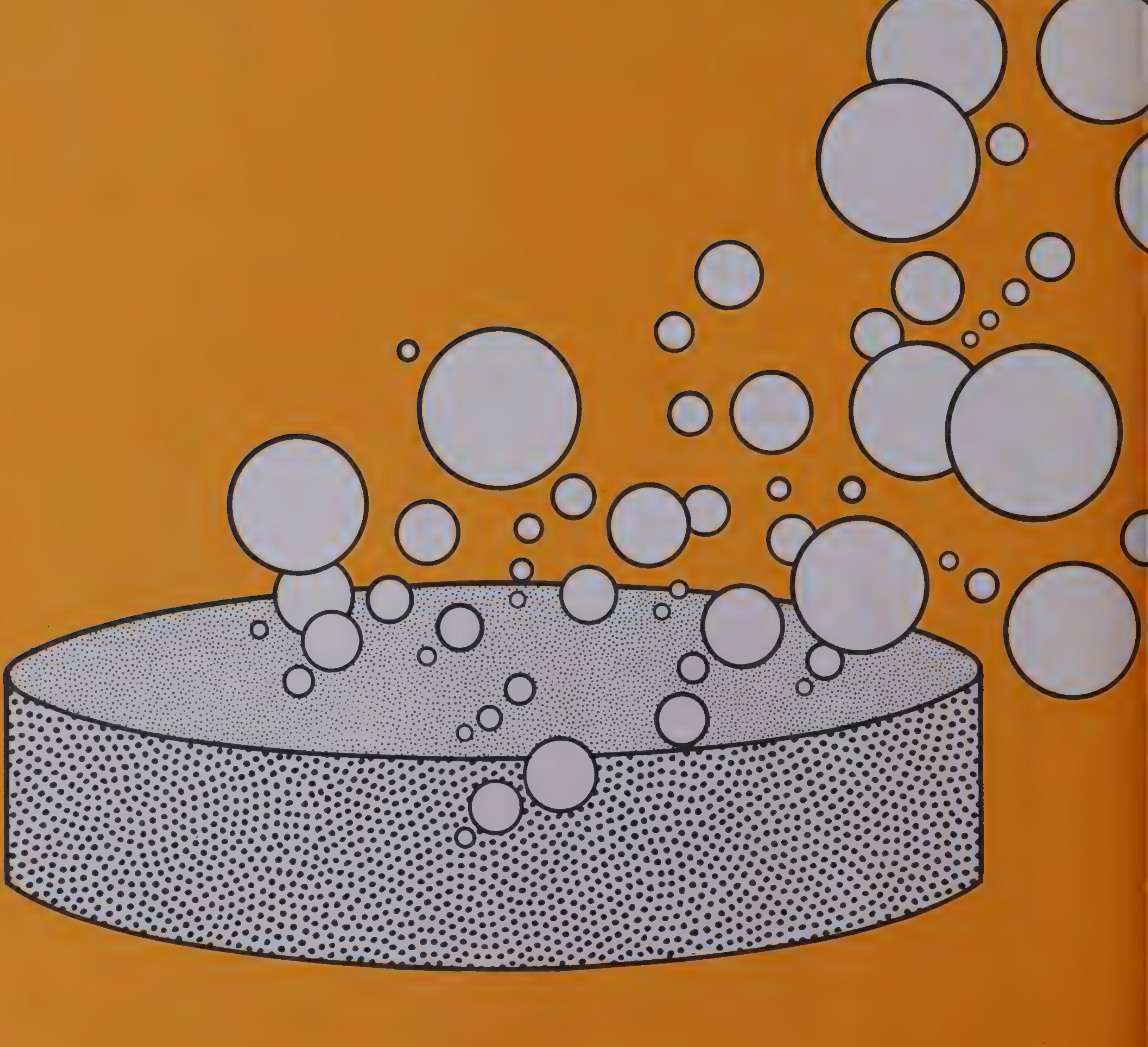
We can still do it, though we have to make use of what we learned from our experiments with floating objects. Tetrabromoethane is a very dense liquid (2900 kg/m^3). It dissolves easily in butyl carbitol (density 960 kg/m^3). The pictures show what happens when samples of the three kinds of sulphur are put in test tubes containing a special mixture of the two together.

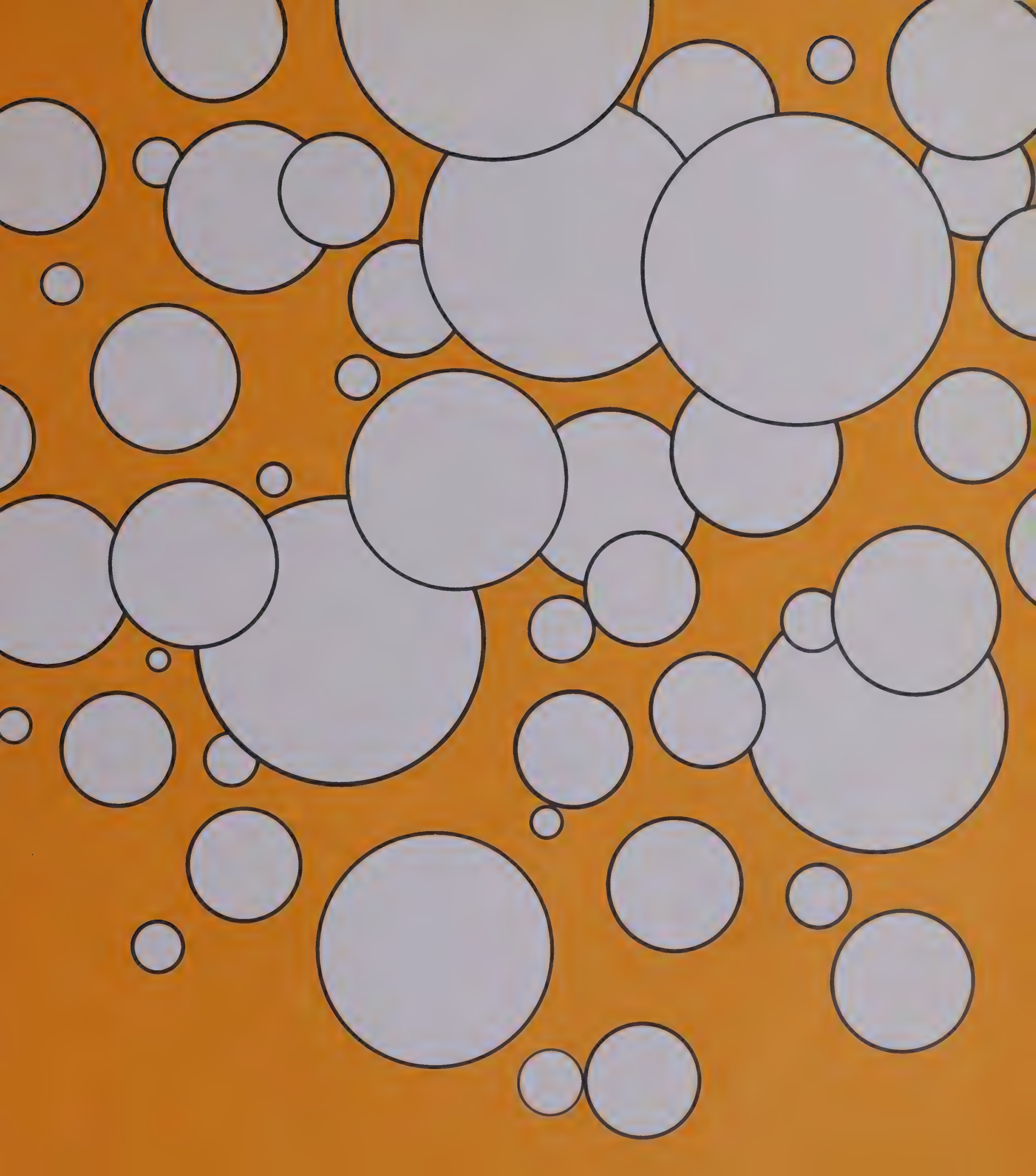
Look at the table of densities and see which materials float in tetrabromoethane.

QUESTIONS:

1. Why do all three kinds float in tetrabromoethane?
2. Why do all three kinds sink in butyl carbitol?
3. Which of the three kinds of sulphur is the most dense? Which is least dense?
4. In which kind of sulphur are the particles packed most densely?
5. In which kind of sulphur are the spaces between particles largest?
6. If sulphur were continuous, with no holes or spaces, would the different kinds of sulphur have different densities?







4.13 Another Kind of Matter

There is a third state of matter which we have so far ignored. We have examined solids and liquids, but we have neglected gases. Air is a gas, though you may know that it is a mixture, not a pure substance. Most of the air is made up of a mixture of oxygen, nitrogen and carbon dioxide. There are also very small amounts of argon, hydrogen, neon and helium. Do gases have mass and take up space just like all the other kinds of matter? This is the problem examined in our next investigation.

4.14 Investigation: Gases / Mass, Volume and Density

PROBLEM: DO GASES HAVE MASS, VOLUME AND DENSITY?

MATERIALS:

Alka-Seltzer tablets and bottle with cap
equal-arm balance
100 ml graduated cylinder
500 ml beaker

PROCEDURE A:

Put a tablet and the bottle filled one-third full of water on the balance and determine their mass carefully. Drop the tablet into the water and watch it fizz. Measure the mass again when the fizzing stops.

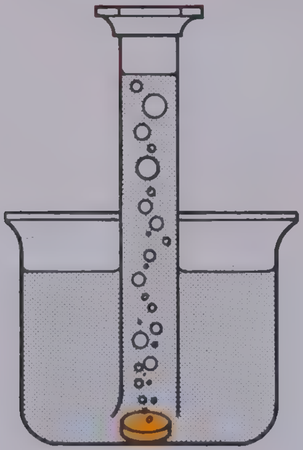
What should happen if you do this part of the investigation in a sealed container? Would the mass still decrease?

OBSERVATION A:

1. What is the mass before fizzing?
2. What is the mass after fizzing?
3. What is the mass of gas released?

PROCEDURE B:

Fill the graduated cylinder with water and invert it in a 500 ml beaker of water. Make sure there are no air bubbles in the cylinder. Drop the tablet into the water and cover it with the cylinder to collect the gas. You may have to break the tablet in half and do each half separately if more than 100 ml of gas is collected.



OBSERVATION B:

1. What is the volume of the gas released?
2. What is the mass of the gas?
3. What is the density of the gas?

4.15 Summary

1. Density measures the packing of particles. It is calculated by dividing an object's mass by its volume. $D=\frac{M}{V}$
2. Density is measured in units of kilograms per cubic metre (kg/m^3) or, sometimes, grams per millilitre (g/ml).
3. The density of an object does not depend on its size or shape.
4. Floating objects are less dense than the liquids they float in.
5. A floating object sinks deeper into less dense liquids.
6. The forms of sulphur have different densities, perhaps because the sulphur particles are arranged differently in each.
7. All three states of matter have mass, volume and density.

4.16 Further Investigations

1. What is the density of a sponge? Should you count the holes or not? Find the density with and without.
2. What is the density of an oil tanker? What is the density of a submerged submarine? What is the density of a person?
3. Why does an oil spill form a layer on the surface of the ocean?
4. Does a ship float higher in salt water or fresh water? Test your theory with the wooden hydrometer.
5. Is a thick or viscous liquid also a dense liquid? What about oil?
6. Measure the mass of the wooden hydrometer with a spring balance as you lower it centimetre by centimetre into water. What does this tell you about floating?

The Density of the Earth

The mass of the Earth is about 5 983 000 000 000 000 000 000 000 kg. This number is often written as 5.983×10^{24} kg. The volume of the Earth can be calculated from its radius, and turns out to be 1 083 300 000 000 000 000 000 m^3. This number is written in scientific notation as 1.0833×10^{21} m^3.

The density of the Earth is:

$$D=\frac{5\,983\,000\,000\,000\,000\,000\,000\,000\text{ kg}}{1\,083\,300\,000\,000\,000\,000\,000\text{ m}^3}$$
$$=\frac{59\,830\,000}{10\,833}\text{ kg/m}^3$$
$$=5523\text{ kg/m}^3$$

Geologists tell us that the average density of rocks on the surface of the Earth is 2800 kg/m^3, much less than the number calculated above. The interior of the Earth must be quite different from the surface.

The Density of Saturn

Most small telescopes will give you an excellent view of the planet Saturn with its unique system of rings. With patience, you may even be able to locate Titan, the largest of its moons, in orbit around it.

The mass of Saturn is 94 times as much as the Earth, but its volume is 845 times as much. Do you see that this makes it much less dense than the Earth?

Since the density of the Earth is 5523 kg/m^3, the density of Saturn is:

$$5523\times\frac{94}{845}=614\text{ kg/m}^3$$

This makes Saturn less dense even than water (at 1000 kg/m^3), and means that, if a large enough ocean could be found, it would float.

4.17 Review

1. Calculate the densities of each of the following objects:

	mass (g)	volume (ml)
(a)	56	18
(b)	67.4	39.5
(c)	88.97	88.96
(d)	0.056	163
	mass (kg)	volume (m^3)
(e)	400	0.25
(f)	917	0.78
(g)	51 900	4.72
(h)	6 200 000	3100

2. Which one of the above materials is most likely (a) a gas? (b) water?
3. A block of wood measures 4.5 cm by 7.0 cm by 18.0 cm. It has a mass of 419 g.
   (a) What is its volume in cubic centimetres?
   (b) What is its volume in millilitres?
   (c) What is its density in grams per millilitre?
   (d) What is its density in kilograms per cubic metre?
   (e) Will this block float in a liquid with a density of 800 kg/m^3? Why?
4. Iron is more dense than water, yet iron ships float. Briefly, why?
5. Could every cubic metre inside a ship be filled with cargo, ordinarily? Explain.
6. Will butter float in water? Will it float in milk?
7. Will nickel float in mercury?
8. You should be able to float in water with only a centimetre or two of your nose out of water. What must your density be, approximately?
9. A block of metal measures 50 cm by 35 cm by 20 cm. It has a mass of 313.6 kg.
   (a) What is its volume in cubic centimetres?
   (b) What is its volume in millilitres?
   (c) What is its volume in cubic metres?
   (d) What is its density in grams per millilitre?
   (e) What is its density in kilograms per cubic metre?
   (f) What metal is this?
10. A block of wood has a volume of 20 m^3 and a density of 0.85 kg/m^3. What is its mass?
11. A bathtub contains 0.85 m^3 of a liquid with a density of 0.70 kg/m^3. What is the mass of the liquid?
12. A cube of metal has a density of 1000 kg/m^3 and a mass of 2500 kg. What is its volume?
13. A wooden block has a density of 0.85 g/ml and a mass of 50 g. What is its volume in millilitres?

Freezing and the Density of Water

Life on the Earth depends on many special properties of matter. One of these involves the density of water as it freezes. Most liquids become more dense as they freeze: their particles stick together with fewer and smaller spaces between them. Because of the special way water particles stick together, ice has more space inside it than does water and is less dense than water. This is the reason that ice floats on water. If water did not have this property, there would be no chance for life as we know it to exist on the Earth.

Think of what would happen if water suddenly changed next winter to a more ordinary material which became more dense as it froze. Any ice that formed would sink to the bottom, forcing warmer water up. Cold air blowing over the surface of the water would cool it and freeze it. This new ice would sink and force more warm water up. Very soon all of our lakes and rivers would be frozen solid and everything living in them would be frozen. In fact, when water freezes, the ice floats on top, protecting the water below from the cold air above. Of course, if winter lasted a lot longer, the water *would* all freeze.

In the spring, the top surface of our new kind of ice would be heated by the sun and by warm air blowing over it. It would melt, but would form an insulating layer over the rest of the ice. It would take many times longer to thaw the whole lake, probably longer than the six months of spring and summer. The oceans have a lower freezing point than fresh water, but once freezing started, it would inevitably freeze them solid, permanently. No life could exist in this never-ending cold.

4.18 Instructional Objectives

1. To calculate the density of any object given its volume in cm^3, ml, ℓ or m^3 and its mass in g or kg. The answer should be in g/ml or kg/m^3.

2. To find the density of a sample, given standard laboratory equipment.

3. To draw a graph, given a set of points, with properly labelled axes.

4. To interpolate and extrapolate from a given graph: that is, to retrieve information expressed in graphic form.

5. To explain the connection between the particle theory and density, in solids, liquids and gases.

6. To identify floating objects by their densities and the density of the liquid in which they are placed.

7. To use the particle theory to explain the densities of the various forms of sulphur.

4.19 Glossary

amorphous sulphur
buoyancy
density
extrapolate
float
hydrometer
interpolate
monoclinic sulphur
rhombic crystals

A TABLE OF DENSITIES
(kilograms per cubic metre)

hydrogen gas	0.0899
helium	0.1785
neon	0.8999
nitrogen	1.2506
air	1.293
oxygen	1.429
carbon dioxide	1.977
methyl alcohol	810
water	1000
sea water	1025
heavy water	1105
mercury	13 546
balsa wood	340
white pine	430
oak	750
butter	860
ice	917
sugar	1540
salt	2180
aluminum	2699
iron	7874
nickel	8902
copper	8960
silver	10 500
gold	19 320
osmium (the most dense metal)	22 570

Heat & Temperature

✓5.1 What Are Heat and Temperature?
5.2 Effect of Heat on Matter
5.3 Investigation: Heat / Water
5.4 Heating Liquids: Effect on Mass
5.5 Investigation: Temperature Increase / Amount of Matter
5.6 Heating Liquids: Effect of Type of Liquid
5.7 Investigation: Heat and Different Liquids
5.8 Measuring Quantities of Heat
5.9 Transfer of Heat
5.10 Investigation: Heat Transfer in Water
5.11 Sample Problem on Mixtures
5.12 Heat Capacity of Metals
5.13 Investigation: Heat Content of Different Metals
5.14 What Have We Learned about Heat?
5.15 Summary
5.16 Further Investigations
5.17 Review
5.18 Instructional Objectives
5.19 Glossary

5.1 What Are Heat and Temperature?

In the preceding chapters we have investigated some of the properties of solid and liquid matter to see if we could devise a model which would help us to understand the structure of all matter. Our investigations of mixtures, solutions, crystals and density have uncovered some valuable insights into the nature of this model. During some of these investigations we observed the results of heating various substances. In this chapter, we will begin to make a more detailed study of the effects of heat.

Heat and temperature represent different concepts. A cup of boiling water has a very high temperature but may contain less heat than a bathtub full of lukewarm water. Heat is something which may be added to matter or taken away from matter, whereas temperature refers to the concentration of heat contained within matter at any time. In the previous chapters we used a Celsius thermometer. Which of these, heat or temperature, does a thermometer measure? As we study heat, always try to use the words heat and temperature in their proper context.

5.2 Effect of Heat on Matter

If heat is something which can be added to matter, then what is the effect on the substance to which it is added? The substance becomes "hotter" (i.e., has a higher temperature) as heat is added; in fact, some substances may even melt, or catch fire. Are there other measurable changes which may result from the addition of heat? Perhaps such changes will provide us with an idea about the nature of heat.

5.3 Investigation: Heat / Water

PROBLEM: WHAT EFFECT DOES THE STEADY ADDITION OF HEAT HAVE ON A LIQUID SUCH AS WATER?

MATERIALS:

500 ml beaker of water
source of steady heat, such as an immersion heating coil
150 ml test tube, with a 1-hole stopper
30 cm length of glass tubing
wooden ruler, calibrated in millimetres

PROCEDURE:

Using the tubing, test tube and rubber stopper, construct the apparatus shown in the diagram. Put a small amount of ink in the water so that it can be seen easily. Be very careful when handling the glass tubing because it breaks easily.

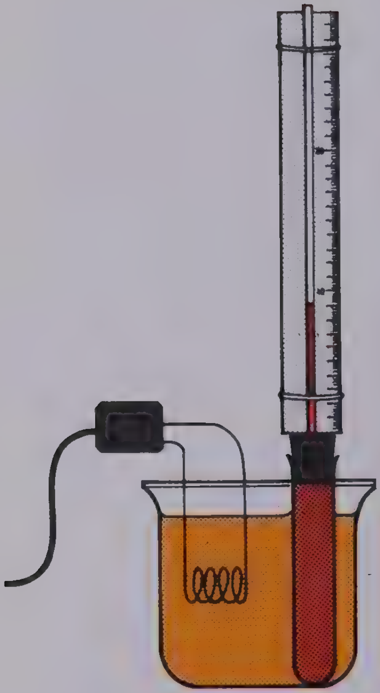
Fasten the ruler to the glass tubing with elastic bands, and support the entire apparatus in such a way that the test tube is

Air and water thermometers were first used in the sixteenth and seventeenth centuries. Galileo's air thermoscope was subject to variations in air pressure and as a result was inaccurate in measuring temperatures.

The Celsius temperature scale, named after Swedish astronomer Anders Celsius, is often called the centigrade temperature scale since it has 100 degrees between the boiling and freezing points of pure water. This scale seems more appropriate to the metric system than the Fahrenheit scale, which has 180 degrees between these two points.

If water expands as it is heated, then of course it should contract as it cools. As water contracts, its particles occupy less space and hence the water becomes more dense – the colder the water, the more dense it becomes. If this is the case, the coldest water in a lake should sink to the bottom, since it is most dense. As a result, lakes should freeze from the bottom up. Why don't they?

Water is a strange substance. As it cools it does contract, but only until it has reached a temperature of about 4°C. For some reason, further cooling causes the water to expand so that as water cools from 4°C down to 0°C, it actually expands and becomes less dense. So you see, the coldest water in a lake which is below 4°C will be found at the surface, so that the lake will freeze from the surface down. This strange behavior is called "the anomalous nature of water". Now, can you explain why pop bottles may crack if the pop inside them freezes?



immersed in the beaker. Place the heating coil in the beaker of water. Be sure that it does not touch the test tube. Turn on the heating coil and record the level of colored water in the glass tubing every 30 seconds until the water in the large beaker nears boiling.

QUESTIONS:

1. Plot a graph of the water level in the tubing at various times during the heating. The heating coil is providing a constant source of heat which is indicated by the length of time of heating. Describe the significance of the shape of your graph.
2. Based on the particle theory of matter, explain what may have caused the water to behave this way when heated.
3. What commonly used device employs the principle you have just discovered?
4. Can you suggest any other liquids which might be more suitable than water for use in such a device? Explain why.

5.4 Heating Liquids: Effect on Mass

When we introduced temperature at the beginning of this chapter, we said it was related to the intensity (concentration) of heat contained in the substance. If equal amounts of heat are added to two different substances, will the increase in the intensity of heat (i.e., temperature) be the same? If equal amounts of heat are added to two different amounts of the same substance, will their temperatures change the same amount? What is the relationship between the addition of heat, temperature increase and amount of matter?

5.5 Investigation: Temperature Increase / Amount of Matter

PROBLEM: WHAT EFFECT DOES THE AMOUNT OF MATTER BEING HEATED HAVE ON THE RATE AT WHICH ITS TEMPERATURE INCREASES?

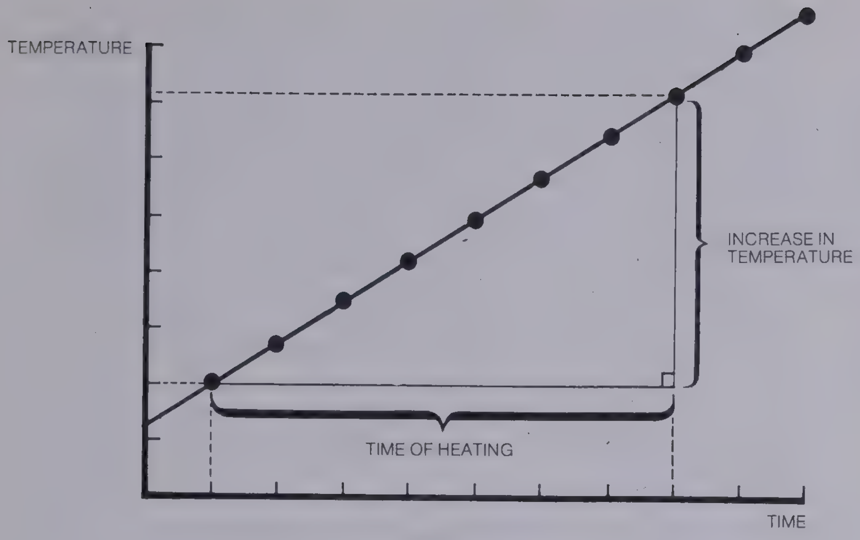
MATERIALS:

250 ml beaker
100 ml graduated cylinder
immersion heating coil
thermometer

PROCEDURE:

Carefully measure out 100 ml of cold tap water into the beaker and record its original temperature. Immerse the heating coil in the water, turn it on and record the water temperature every minute until it nears the boiling point. Repeat the same procedure with 200 ml of tap water, starting at the same initial temperature and using the same heating coil.

Plot temperature versus time graphs for each of the two water samples, and label them. For each sample, choose a straight line portion of the graph and calculate the rate of temperature increase, in °C/min, as follows:

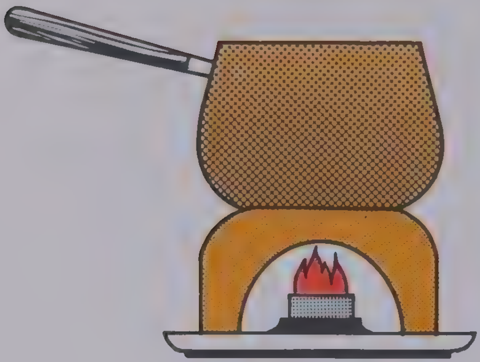


$$\therefore \text{RATE OF TEMPERATURE INCREASE} = \frac{\text{INCREASE IN TEMPERATURE}}{\text{TIME OF HEATING}}$$

Compare these rates for each sample, and describe the effect that mass has on the heating rate of a liquid.

QUESTIONS:

1. What evidence is there, from your graphs, that the heating coil was providing a constant source of heat?
2. If a 50 ml sample and a 400 ml sample of water were also heated by the same heating coil, estimate their rates of temperature increase, and sketch heating curves for each of these samples on your graph.
3. If 80 ml of water are heated from 20°C to 50°C in six minutes, how long would it take to increase the temperature of 120 ml of water the same amount using the same heating coil?
4. What is the relationship between the mass of a substance and the amount of heat required to produce a given temperature change?



5.6 Heating Liquids: Effect of Type of Liquid

Our last investigation showed us that the amount of matter being heated had a direct effect on the rate at which the temperature increased when heat was added to the matter. Since a 200 ml sample of water would have twice as many particles as a 100 ml sample, it should, therefore, require twice as much heat to produce the same intensity of heating of its particles. What other factors might affect the amount of heat required to increase the temperature of a substance? Since temperature is related to the intensity of heating of the particles of a substance, then perhaps the type of particle of which the substance is composed will affect the rate at which its temperature increases. Different substances may require different amounts of heat to produce the same temperature increase. In other words, all substances may not have the same capacity to hold heat.

Why do meats cook faster in oil than in water of the same temperature? Which do you suppose would take longer to heat to cooking temperature – the cooking oil, or water? Can you relate the answers to these two questions?

5.7 Investigation: Heat and Different Liquids

PROBLEM: WILL SAMPLES OF TWO DIFFERENT LIQUIDS, HEATED BY THE SAME SOURCE OF HEAT, INCREASE IN TEMPERATURE AT THE SAME RATE?

MATERIALS:

2 identical beakers
100 ml graduated cylinder
water and antifreeze
immersion heating coil
thermometer

PROCEDURE:

Starting from room temperature, heat 100 ml of water using the heating coil. Record the temperature every minute until it exceeds 80°C. Repeat exactly the same procedure, using 100 ml of antifreeze.

On one piece of graph paper, plot temperature versus time graphs for both substances and label them. Determine the rate of temperature increase for each liquid (as done in the previous investigation) and compare these rates.

QUESTIONS:

1. Which substance, water or antifreeze, receives more heat from the coil in one minute?
2. Explain why the same amount of heat could cause a greater temperature increase in one liquid than in the same amount of the other liquid.
3. Which has the greater heat capacity, water or antifreeze? That is, which substance requires more heat to increase its temperature by a given amount?

Antifreeze is made from a chemical called ethylene glycol which freezes at –17°C

5.8 Measuring Quantities of Heat

So far in our study of heat and temperature we have limited ourselves to investigating the effects of heat on matter. We have seen that the addition of heat can cause an increase in temperature which we can measure with a thermometer. It is also of great importance to our understanding of heat to devise a way of measuring the amount of heat that is added to or taken away from a substance.

We have seen that the amount of heat required to increase the temperature of a substance depends on three factors:

1. the mass of the substance being heated
2. the type of substance being heated or, more specifically, its heat capacity
3. the increase in temperature of the substance

Quantities of heat are measured in units called joules (J). We will be able to define more clearly what a joule of heat is later (in Chapters Eight and Nine), when our understanding of the nature of heat has improved. We do know what effect 1 J of heat has on water due to the work of a British physicist, James Prescott Joule, after whom the unit was named. As a result of very careful experimentation around the middle of the last century, Joule determined that approximately 4.2 kJ of heat are required to raise the temperature of 1 kg of water 1°C. This relationship is called the specific heat capacity of water, and may be written as follows:

$c = 4.2\ \text{kJ}/(\text{kg}\cdot{}^{\circ}\text{C})$ where c is a symbol used to represent the specific heat capacity of water

Similarly, we could determine the specific heat capacity of other substances, such as the antifreeze in our last investigation, by comparing their rates of temperature increase with that of water. For example, a liquid whose temperature increases twice as fast as that of an equal amount of water would have a specific heat capacity which is only half that of water: i.e., 2.1 kJ/(kg · °C).

Using this definition of specific heat capacity together with the findings of our previous two investigations, we can conclude that the amount of heat required to change the temperature of a substance by a given amount can be calculated using the following formula:

$$H = m \times \triangle T \times c$$

where H = quantity of heat added in kJ
m = mass of substance being heated in kg
$\triangle T$ = change in temperature in °C
c = specific heat capacity of substance in kJ/(kg · °C)

Before the real nature of heat was known, other units were developed to measure quantities of heat. Two of these units, the calorie and the British Thermal Unit, are still used today, although in the metric system they are discouraged.

1 calorie is the amount of heat necessary to increase the temperature of 1 g of water by 1°C

1 BTU is the amount of heat necessary to increase the temperature of 1 pound of water by 1°F

As you can see, 1 calorie and 4.2 J both represent the same amount of heat.

Although the calorie is still in widespread use, the joule is the much preferred unit of heat in the metric system

*In the laboratory, we often use amounts of water whose mass is more conveniently expressed in grams rather than kilograms.
Although the specific heat capacity of water is 4.2 kJ/(kg · °C)
since 1 kJ = 1000 J
and 1 kg = 1000 g,
in the lab it is often convenient to think of specific heat capacities in J/(g · °C)
NOTE 4.2 kJ/(kg · °C) = 4.2 J/(g · °C)

EXERCISE

Use the formula to determine the amount of heat gained or lost in each of the following situations:

1. 15 g of water is heated from 12°C to 32°C
2. the temperature of 24 g of water rises by 40°C
3. 150 g of water is cooled from 80°C to 60°C
4. the temperature of 48 ml of water drops by 30°C

Try to determine the temperature change in each of the following situations:

5. 10 g of water gains 1890 J
6. 25 ml of water gains 1050 J
7. 80 ml of water loses 1680 J
8. 100 g of water loses 6720 J

Try to use the following information to determine the specific heat capacities of the substances involved:

9. 3000 J of heat added to 50 g of the substance causes its temperature to rise by 20°C
10. 80 g of the substance loses 2880 J of heat, causing its temperature to drop 15°C

5.9 Transfer of Heat

When you pour a cup of coffee, the coffee is at a higher temperature than the cream that you add. The mixture of coffee and cream has a lower temperature than just hot coffee. When the cream and coffee are mixed, two temperature changes occur: the temperature of the coffee decreases while the temperature of the cream increases. When the two liquids at different temperatures are mixed, they both arrive at the same temperature, which lies somewhere between their original temperatures.

To accomplish this, the coffee must lose some heat and the cream must gain some. Could we calculate the amount of heat lost by the coffee as it cools or the amount of heat gained by the cream as it warms up? Are these two quantities of heat related? Where does the heat gained by the cream come from? Where does the heat lost by the coffee go? What factors will determine the final temperature of the mixture?

The answers to these questions are related to the mechanism by which heat can be transferred from the hot coffee to the colder cream. We will attempt to discover the basis of this process of heat transfer in our next investigation.

5.10 Investigation: Heat Transfer in Water

PROBLEM: WHAT DETERMINES THE AMOUNT OF HEAT TRANSFERRED WHEN SAMPLES OF HOT AND COLD WATER ARE MIXED?

MATERIALS:

several large styrofoam cups
100 ml graduated cylinder
thermometer

PROCEDURE:

Measure out 100 ml of hot tap water into a styrofoam cup and 100 ml of cold tap water into another styrofoam cup.

Measure the temperatures of each of these water samples and then *immediately* mix them together, using the thermometer to gently stir the mixture. Measure the temperature of the mixture immediately after mixing and stirring. Repeat the procedure with the following combinations:

1. 100 ml cold and 75 ml hot
2. 100 ml cold and 50 ml hot
3. 100 ml cold and 25 ml hot
4. 75 ml cold and 100 ml hot
5. 50 ml cold and 100 ml hot
6. 25 ml cold and 100 ml hot

Using the formula developed in the previous section, calculate the amount of heat lost by each hot water sample, and the amount of heat gained by each cold water sample. Record these calculations in a table.

Be sure to include the following: the temperature change of the cold water for each sample of cold water, the amount of heat gained by the cold water for each sample of cold water, the temperature change of hot water for each sample of hot water and the amount of heat lost by the hot water for each sample of hot water.

Compare the amounts of heat lost and gained in each of the mixtures. Try to formulate a principle regarding the transfer of heat between two substances at different temperatures when they are mixed.

The notion that heat can only pass from a hotter to a colder object is known as the second law of thermodynamics.

Thermodynamics is the study of the interrelations of heat and mechanical energy. You will explore the concept of mechanical energy in Chapters Eight and Nine.

QUESTIONS:

1. If the amount of heat lost by the hot water is not equal to the amount of heat gained by the cold water, which should be greater, and why?
2. Try to determine the final temperature of each of the following mixtures:
   (a) 100 ml of water at 10°C with 100 ml of water at 70°C
   (b) 200 ml of water at 10°C with 100 ml of water at 70°C
   (c) 300 ml of water at 10°C with 100 ml of water at 70°C

5.11 Sample Problem on Mixtures

Find the final temperature of a mixture of 50 ml of water at 5°C with 100 ml of water at 95°C.

This problem may be solved by thinking in terms of the "heat" content" of each of the samples before they are mixed. All of the heat contained in both samples is then donated to the mixture and shared by all of the water in the mixture.

The problem becomes much more complicated if the two substances mixed have different specific heat capacities. For example, to find the final temperature of a mixture of 50 g of alcohol ($c = 2.3\ \text{kJ/(kg} \cdot {}^\circ\text{C)}$ at 5°C and 100 g of water at 95°C requires a different type of solution. Perhaps your teacher will show it to you.

$$\text{Heat content of cold water} = 0.05\ \text{kg} \times 5^\circ\text{C} \times 4.2\ \text{kJ/(kg} \cdot {}^\circ\text{C)} = 1.05\ \text{kJ}$$

$$\text{Heat content of hot water} = 0.100\ \text{kg} \times 95^\circ\text{C} \times 4.2\ \text{kJ/(kg} \cdot {}^\circ\text{C)} = 39.9\ \text{kJ}$$

$$\text{Heat content of mixture} = 0.15\ \text{kg} \times ?^\circ\text{C} \times 4.2\ \text{kJ/(kg} \cdot {}^\circ\text{C)} = 40.95\ \text{kJ}$$

Therefore to find the temperature of the mixture which has a mass of 0.15 kg and a heat content of 40.95 kJ, we perform the following calculation:

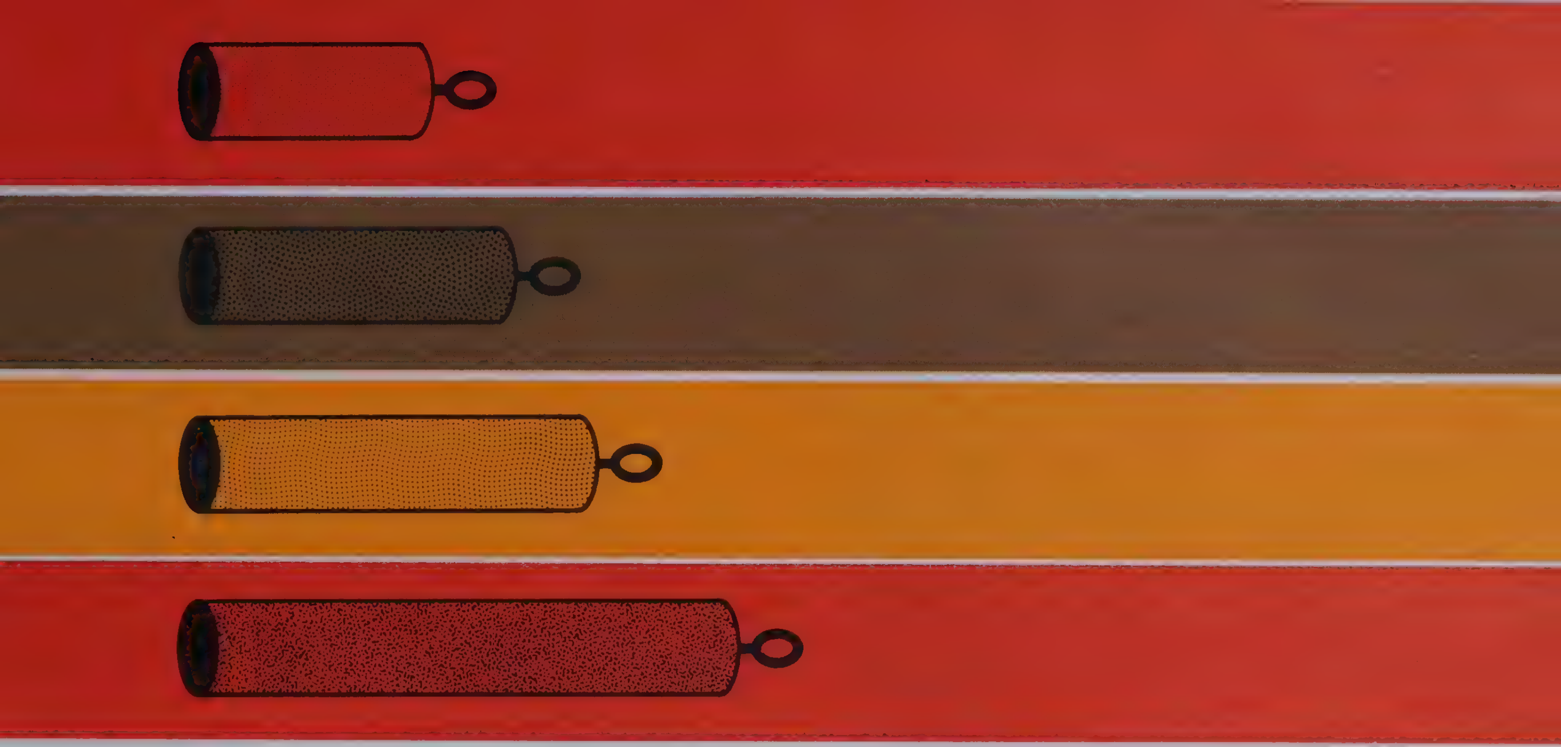
$$\text{Temperature of mixture} = \frac{40.95\ \text{kJ}}{0.15\ \text{kg} \times 4.2\ \text{kJ/(kg} \cdot {}^\circ\text{C)}} = 65\ ^\circ\text{C}$$

These equations can be used to calculate heat transfer in any mixing problem.

5.12 Heat Capacity of Metals

We have seen that it takes about 4.2 kJ of heat to increase the temperature of 1 kg of water by 1°C. We have suggested that this be called the specific heat capacity of water. It tells us how much heat each kilogram of water contains for each degree of its temperature. Investigation 5.4 showed us that antifreeze has a different specific heat capacity than water. Similar experiments with other liquids would reveal that each has its own characteristic specific heat capacity.

Our next investigation deals with the heat capacity of various metals. We must realize that if a hot metal object is placed in a cold liquid, the metal will begin to lose heat and the liquid will begin to gain heat, until they both have reached the same temperature. How will the amount of heat lost by the metal compare with the amount of heat gained by the water?



5.13 Investigation: Heat Content of Different Metals

PROBLEM: DO EQUAL MASSES OF DIFFERENT METALS AT THE SAME TEMPERATURE CONTAIN THE SAME AMOUNT OF HEAT?

MATERIALS:

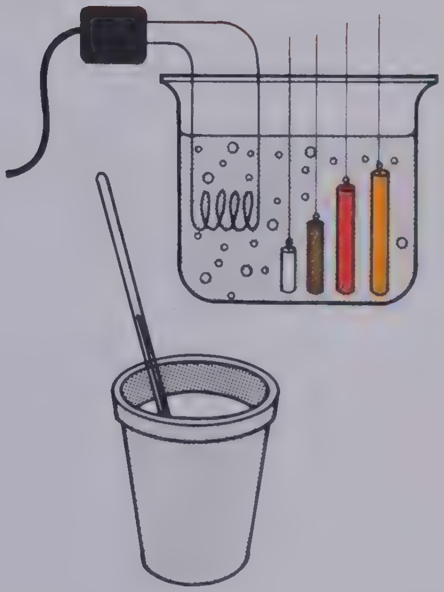
samples of several metals having the same mass
(e.g., aluminum, copper, zinc, lead)
styrofoam cups
boiling water
thermometer

PROCEDURE:

Attach a string to each sample, suspend the metals in a bath of boiling water and allow them to remain there for several minutes. In this way we can be certain that all of the metals are at the same temperature as the boiling water. Measure this temperature.

Measure out 100 ml of cold tap water into a styrofoam cup and record its initial temperature. Then quickly transfer one of the metal samples from the hot water bath to the cold water in the styrofoam cup. Stir gently, and measure the final temperature of the water.

Repeat the same procedure with each of the other metal samples and record your data. For each metal sample, be sure to include: the initial temperature of the metal, the amount and initial temperature of the water (in degrees Celsius) and the final temperature of the water.



CALCULATIONS:

In each case, calculate the amount of heat gained by the cold water. Where did this heat come from? As a result, how much heat did each metal sample lose? Record these calculations in a table.

We have defined the heat capacity of a substance as the heat required to change the temperature of 1 kg of the substance by 1°C. We can determine the heat capacity of each of our metal samples by dividing the amount of heat lost first by its mass and then by its temperature change. Perform these calculations and record the results in a table.

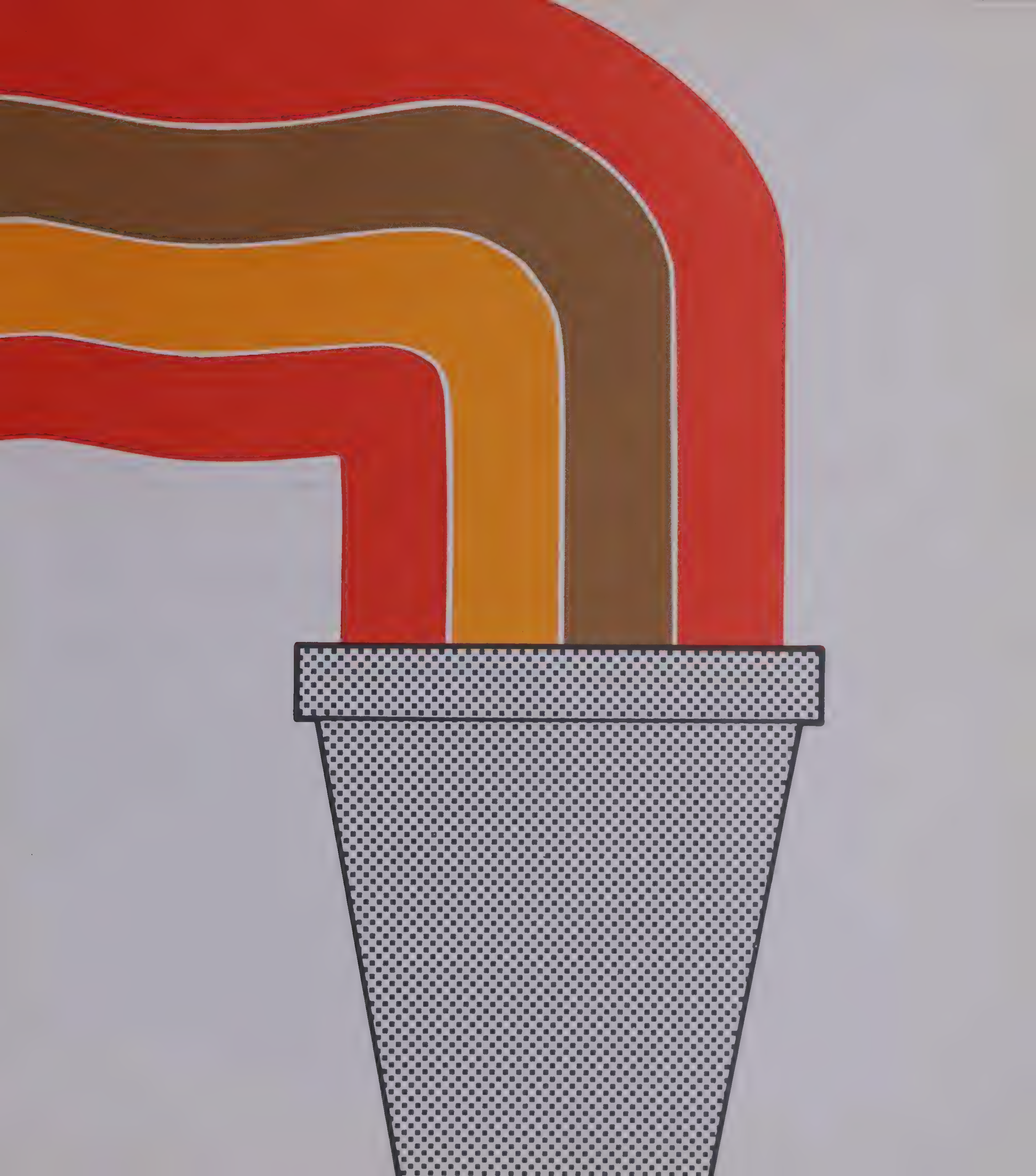
If 50 g of a metal loses 2000 J of heat in cooling from 80°C to 20°C, its specific heat capacity would be

$$\frac{2\,000\ \text{kJ}}{0.05\ \text{kg} \times 60\,°\text{C}} = 0.67\ \text{kJ/(kg} \cdot °\text{C)}$$

QUESTIONS:

1. Arrange the metals in increasing order of specific heat capacity.
2. Arrange the metals in increasing order of density. (How can this be done without actually calculating any densities if you know that all samples have the same mass?)
3. Describe any significant relationship between the density of a metal and its specific heat capacity.
4. Using a reference book from your school library, try to find published values for the specific heat capacities of the metals you investigated and compare your values with these "accepted values". Why might they differ?

Remember:
100 ml of water has a mass of 0.100 kg.



5.14 What Have We Learned about Heat?

The investigations in this chapter have introduced us to a few of the basic properties of heat. We have learned to distinguish between heat and temperature, and have become familiar with the methods of measuring heat and temperature. We have also discovered some of the effects of adding heat to various substances. We are trying to learn enough about heat to enable us to formulate a model for the nature of heat—to tell us what heat is and how it fits into our existing model of the structure of matter.

It seems clear that we need more data, more descriptions of the ways heat can affect matter, before we can attempt to understand its nature. In Chapter Six we will investigate other effects of heat.

5.15 Summary

Specific Heat Capacities of Some Common Substances in kJ/(kg · °C)

ice	2.1
iron	0.46
mercury	0.14
alcohol	2.3
aluminum	0.92
copper	0.39
lead	0.13
vegetable oil	2.0
glass	0.67
silver	0.24
water	4.2
turpentine	1.7

1. Heat and temperature are two different things. Heat refers to the total amount of heat contained in a substance, whereas temperature is a measure of the intensity of heating associated with each particle of a substance.

2. When a liquid is heated, it expands. The same relationship may exist for solids and gases. This phenomenon forms the basis for measuring temperatures using a thermometer.

3. When heat is added to a substance, the increase in temperature which results depends on the mass of the substance being heated, and on its specific heat capacity.

4. Quantities of heat are measured in units called joules (J). 4.2 kJ of heat are required to change the temperature of 1 kg of water by 1 °C.

5. The amount of heat gained or lost when a substance is heated or cooled is given by:

   $H = m \times \triangle T \times c$

   where H = quantity of heat added in kJ
   m = mass of substance being heated in kg
   $\triangle T$ = change in temperature in °C
   c = specific heat capacity of substance in kJ/(kg · °C)

6. Different substances have different abilities to hold heat. The specific heat capacity of a substance is the number of joules necessary to change the temperature of 1 kg of the substance by 1 °C. The specific heat capacities of metals are much less than the specific heat capacity of water and appear to be related to the density of each metal.

5.16 Further Investigations

1. Could the thermal expansion of a solid be used as the basis for measuring temperature? What would be the major problem with such a thermometer? Can you list any devices which utilize the thermal expansion of a solid?
2. The boiling point and freezing point of pure water are used as the basis for the Celsius temperature scale. Is it necessary that the water be pure? Try to determine the boiling point of a salt and water solution. See if the concentration of salt in the solution has any effect on its boiling point. Would salt have any effect on the freezing point?
3. Prepare a saturated solution of sugar and water at 100°C. Mix 100 ml of this solution with 100 ml of cold tap water in a styrofoam cup and measure the final temperature of the mixture. Compare this temperature with the final temperature of a mixture of 100 ml of pure water at 100°C with 100 ml of cold tap water. Does a sugar solution have a different heat capacity than pure water? See if you can determine the heat capacity of the solution you mixed.
4. Cooling a liquid is much more complicated than heating it. Pour 100 ml of boiling water into a styrofoam cup and record its temperature every 30 seconds. Plot a temperature versus time graph for the water as it cools. Is the graph the shape you expected it to be? If not, can you offer any simple explanation for the loss of heat from a substance which would result in a graph like yours? If you record temperatures for a long enough time, what will the graph eventually do?
5. Place a small container full of boiling water into a larger styrofoam container full of cold water. Measure the temperatures of each of the water samples every minute until they are equal. Repeat this experiment using inner containers of several different materials (styrofoam, paper, plastic, tin, copper, aluminum) and compare the time taken for the two water samples to reach the same temperature. Which substance is the best conductor of heat? Which is the best insulator?

The thermal expansion of a metal plays a key role in the operation of the automatic choke on most new automobiles. Consult an elementary auto mechanics textbook to see how it works

As the salt water solution continues to boil, some water evaporates but no salt does. What does this do to the concentration of the boiling solution? Continue to record the boiling temperature until half the solution has boiled away.

Fill a large paper cup with water and measure its depth. Make a small hole in the bottom of the cup with a nail and allow water to leak from the hole for 5 s. Measure the depth again, and repeat this procedure until no water remains in the cup. Draw a graph of water depth versus time and compare it with your cooling curve. Can you explain the similarity?

5.17 Review

1. Which contains more heat, a cup of hot coffee or a swimming pool on a summer day? Explain.
2. Sketch temperature versus time graphs for each of the following:
   (a) two samples of water, one 50 ml and the other 200 ml, being heated from the same initial temperature by the same source of heat
   (b) two 100 ml samples, one water and the other alcohol, being heated from the same initial temperature by the same source of heat
3. Calculate the amount of heat gained or lost in each of the following:
   (a) 100 g of water cooling from 80°C to 60°C
   (b) 250 ml of water heating up 8°C
   (c) 100 g of aluminum, whose specific heat capacity is 0.9 kJ/(kg · °C), being heated from 20°C to 100°C
4. Use the method outlined in 5.6 to find the final temperature of each of the following mixtures:
   (a) 50 ml of water at 15°C with 150 ml of water at 55°C
   (b) 100 g of water at 5°C with 20 g of water at 77°C
   (c) 50 g of alcohol at 10°C with 80 g alcohol at 75°C, the specific heat capacity of alcohol being 2.3 kJ/(kg · °C).
5. Water has one of the highest specific heat capacities. Explain the relationship between water's heat capacity and the ability of large bodies of water to moderate the climate of the surrounding land.
6. If 50 g of iron loses 840 J of heat in cooling from 80°C to 40°C, determine the specific heat capacity of iron.

How much water at 20°C must be added to 150 g of water at 95°C, so that the final temperature of the mixture will be 50°C?

Why do concrete sidewalks have grooves cut across their surface every 2 m or so, and a narrow strip of soft asphalt-type material between sections of sidewalk every 20 m or so?

Why does a wooden floor in a room feel colder to bare feet than a rug does?

5.18 Instructional Objectives

1. To explain clearly the difference between heat and temperature and to give examples of each.

2. To describe the expansion of a liquid when heated and to offer an explanation of this expansion, which might be applicable to solids and gases as well, in terms of the particle theory.

3. To state the effect of mass and specific heat capacity on the amount of heat required to produce a given temperature change in a substance.

4. To state the unit used to measure quantities of heat.

5. To define the specific heat capacity of a substance and to state the value of the specific heat capacity of water.

6. To state and use accurately the formula for determining the amount of heat lost or gained when a substance changes temperature.

7. To state the fundamental principle of heat exchange governing the transfer of heat when two substances at different temperatures are mixed.

8. To solve heat transfer problems involving the mixture of two different amounts of the same substance, initially at different temperatures, by determining the final temperature of the mixture.

9. To compare the specific heat capacities of various metals with the heat capacity of water, and to offer an explanation of the relationship between the specific heat capacity of a metal and its density.

10. To determine, using the principle of heat transfer, the specific heat capacity of a metal.

5.19 Glossary

heat exchange
heat transfer
Joule
specific heat capacity

Changes of state

6.1 Solids, Liquids and Gases: Changes of State
6.2 Melting: How Does a Solid Become a Liquid?
6.3 Investigation: Volume / Melting
6.4 Investigation: Mass / Melting
6.5 Heat, Temperature and Melting
6.6 Investigation: Heat / Melting
6.7 Investigation: Melting Ice
6.8 The Melting and Freezing of a Solution
6.9 Investigation: Antifreeze / Melting Point
6.10 Heat, Temperature and Boiling
6.11 Investigation: Boiling / Melting
6.12 The Boiling Point of a Solution
6.13 Investigation: Antifreeze / Boiling Point
6.14 What Is Steam?
6.15 Investigation: Boiling and Condensing / Volume Changes
6.16 Exercise: Estimating Particle Spacing
6.17 A Question about Steam
6.18 Boiling under Reduced Pressure
6.19 Investigation: Boiling Point / Reduced Pressure
6.20 Sublimation
6.21 Investigation: Solid to Gas
6.22 Solids, Liquids and Gases: Some Possible Answers
6.23 Summary
6.24 Further Investigations
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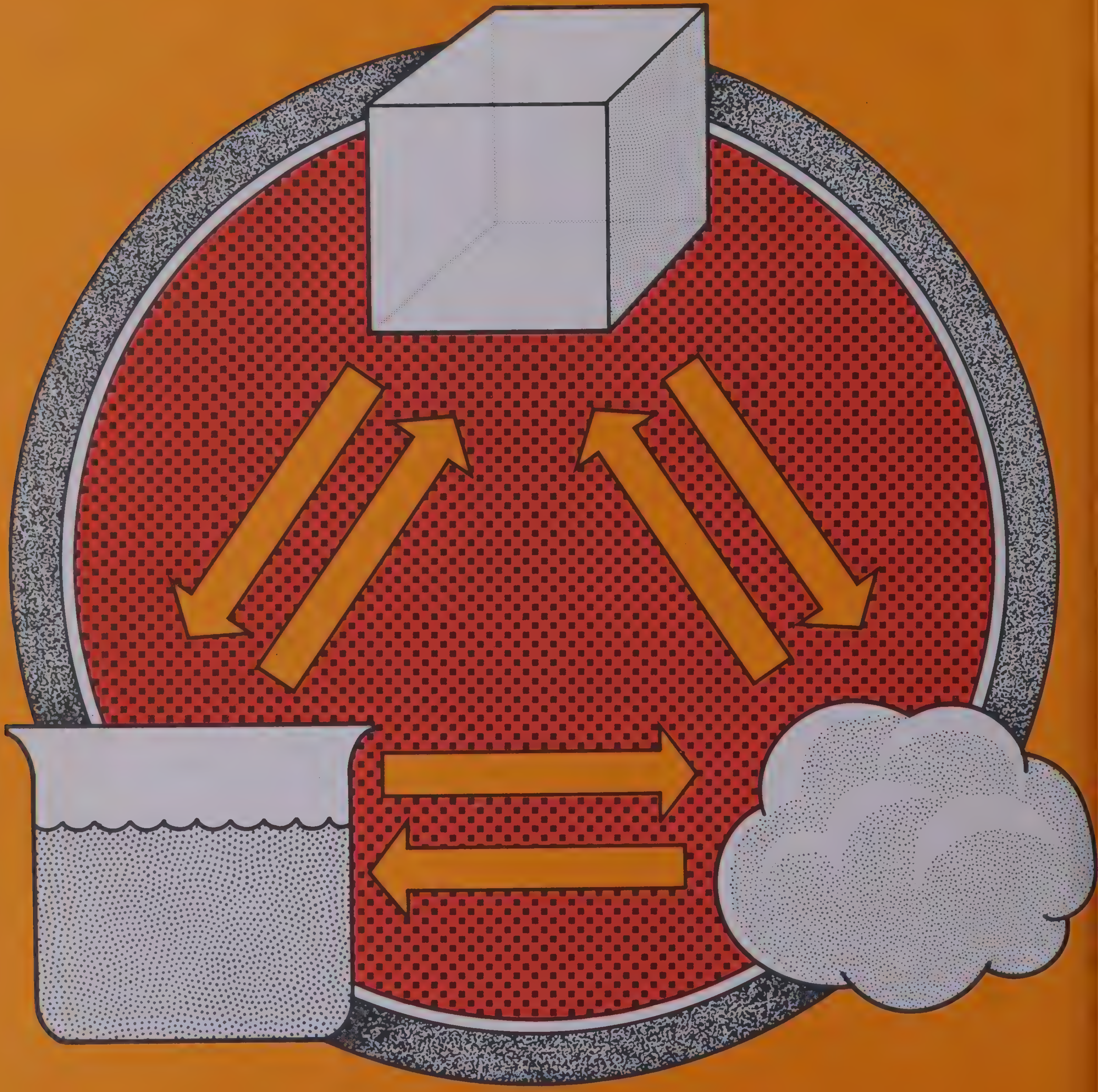


6.1 Solids, Liquids and Gases: Changes of State

Water is a very special substance. It is the only pure substance that exists at normal temperatures in all three states, a solid, a liquid and a gas. In winter, you can easily find solid water, as ice, frost and snow. At the same time, the water beneath the ice on rivers is still a liquid. Finally, it is found as a gas called water vapor, mixed with other gases in our atmosphere.

When groups of water vapor particles clump together they form water droplets, which can be seen as clouds or fog. When the drops grow too big, it rains. A combination of smoke and fog particles also forms, and is commonly known as smog.

Other pure substances are normally solids, or liquids or gases. At room temperature, water is a liquid, sulphur is a yellow solid and oxygen is a clear, colorless gas. If you heated them, all three would be gases at 450°C. Cooled below –220°C, all three will be solids. There is no one temperature at which all three are liquids. By heating or cooling, most materials can be changed from one state to another.

The names of most of the changes of state are well known, but there are a few you may not be aware of. The following table shows some that you should know:

CHANGE OF STATE	NAME
solid to liquid	melting, fusion
liquid to gas	boiling, evaporation
solid to gas	sublimation
gas to liquid	condensation, liquifaction
liquid to solid	freezing, solidification
gas to solid	sublimation

We have shown how a particle model explains some of the observations we have made about the nature of matter. We have seen matter breaking up during dissolving and assembling itself during crystallization. We have explained the patterns produced by salol crystals by assuming they represented different particle arrangements.

We have shown how heat influences all of these processes. Heat speeds up dissolving and usually allows more solute to dissolve. Heat is released or absorbed as crystals dissolve. The rate of cooling controls the size and regularity of crystal growth, and can control the shape of the crystals produced. Different kinds of matter, even at the same temperature, usually contain different amounts of heat. Our particle model does not include any explanation for this observation.

We have not tried to find out what heat is, or how it really affects matter. Some investigations involving changes of state will provide more evidence for what heat does, or what it is.

Solids have a definite shape and volume. Liquids have a definite volume but no definite shape. Gases have no definite shape or volume

A vapor is the gaseous state of a substance which at normal room temperatures (about 20°C) is a solid or a liquid. Substances which are normally in the gaseous state at room temperature are called gases.

Gases	*Vapors*
oxygen	water vapor
carbon dioxide	alcohol vapor
nitrogen	gasoline vapor

Even a solid such as iron can become a liquid if heated to 1535°C or a vapor if heated to 3000°C

Most common gases are clear, colorless and hence difficult to detect. Many are toxic and can result in death if overexposure occurs.

Gas	*Color*	*Odor Toxicity*
oxygen	clear colorless	none essential to life
carbon dioxide	clear colorless	none product of human respiration
nitrogen	clear colorless	none major constituent of air
carbon monoxide	clear colorless	none lethal if inhaled in quantity
sulphur dioxide	clear colorless	choking odor poisonous and irritating
nitrogen dioxide	dark brown	choking odor poisonous and irritating
bromine	dark brown	choking odor poisonous and corrosive
iodine	dark purple	choking odor poisonous and irritating
chlorine	pale yellow	choking odor poisonous and irritating
ammonia	clear colorless	choking odor poisonous and irritating

6.2 Melting: How Does a Solid Become a Liquid?

The change of state from a solid to a liquid occurs frequently. How well understood is this change? In our investigations, we will consider:

1. Does volume change during melting?
2. Does mass change during melting?
3. Does temperature change during melting?
4. Is heat absorbed or released during melting?
5. How much heat is needed for melting?
6. Do dissolved substances affect melting?
7. What does heat do during melting?

Another name given to the process of melting is fusion.

The temperature at which a solid becomes a liquid is called its melting point. Each substance has its own characteristic melting point which depends on the type of particles of which the substance is composed and their degree of attachment together in the solid state.

Melting Points of Some Common Substances
(in °C)

water	0	platinum	1760
aluminum	658	tungsten	3400
iron	1535	nitrogen	–210
lead	327	oxygen	–219
tin	232	hydrogen	–259
copper	1080	helium	–271
gold	1063		
silver	962		

6.3 Investigation: Volume / Melting

PROBLEM: DOES THE VOLUME OF MATTER CHANGE DURING MELTING?

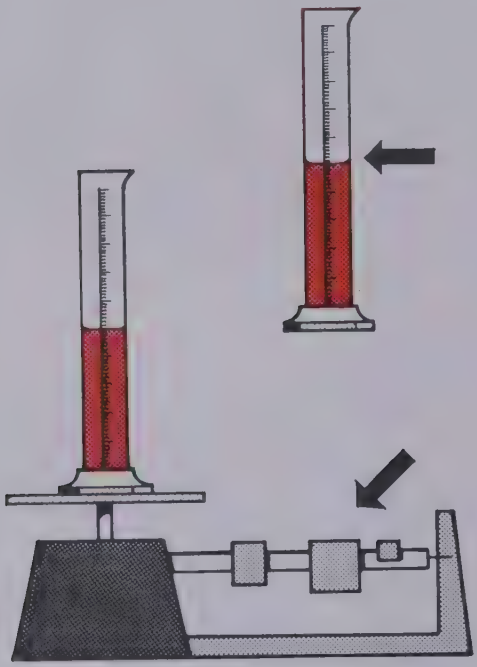
MATERIALS:

100 ml graduated cylinder
ice cubes

PROCEDURE:

Fill a graduated cylinder with 50 ml of hot water. Drop several ice cubes into this water, and, pushing them under water with the tip of a pencil, measure the total volume of ice and water. Wait until the ice has all melted, and then measure the volume again. Repeat. Tabulate the data in a chart.

For both samples, record the volumes of the following: hot water; water and ice; ice; the volume after melting; the volume of the melted ice.



QUESTIONS:

1. Does the volume of ice change during melting? If so, how does it change?
2. Has any matter been added or removed from the graduated cylinder during the process of melting?
3. How can the volume change? If ice is made up of particles, what must happen to the distance between particles to explain any volume changes you observed?
4. How much would the volume of 100 ml of ice change during melting?

Once again the problem of amount of matter arises. Which is the better indicator, mass or volume? When we dissolved alcohol in water and salt in water, the total volume of the solution changed. The mass of the solution remained constant. We explained this by imagining tiny spaces between the particles, which are partially filled by other particles during mixing. Now, during melting, the volume of a substance has once again changed. Do you think that matter is lost during melting? Did some matter disappear? Are there the same number of water particles after melting as before? What do you think would happen if we measured the mass of the melting ice as it melts? Would it decrease also?

6.4 Investigation: Mass / Melting

PROBLEM: DOES THE MASS OF MATTER CHANGE DURING MELTING?

MATERIALS:

100 ml graduated cylinder
equal-arm balance
ice cubes

PROCEDURE:

Repeat Investigation 6.3, but this time determine the mass of the ice and water instead of measuring the volume. Do not remove the cylinder from the balance until melting is completed. Repeat with a second sample. Record your data in a table.

For both samples record the mass of the following: the cylinder and water; the cylinder, water and ice; the ice; the cylinder, water and melted ice; the melted ice.

QUESTIONS:

1. What should the mass of 100 g of ice be after melting?
2. Explain why the mass did or did not change, using the particle theory of matter.
3. Is mass or volume the better way to measure an amount of matter? Why?

6.5 Heat, Temperature and Melting

The North Pole is covered by ice three to six metres thick in winter, but by summer most of it has melted. What does this tremendous amount of water do to the sea level? If all the ice floating in the Arctic and Antarctic Oceans were to melt, what would happen?

To see for yourself, get an ice cube, put it in water and watch the water level as the ice cube melts. Surprised?

The ice is being supported by the water around it as it floats. If the ice were more dense, it would sink deeper, but it doesn't. Mentally remove the ice from the water, leaving a hole in the water. Now fill the hole (mentally) with water. Obviously this amount of water just fills the hole. Plainly, the ice cube must have exactly the same mass as the water it displaces (this works for any floating object). If the ice melts, it will produce just enough water to fill the hole it used to make in the water, and the water level will not rise.

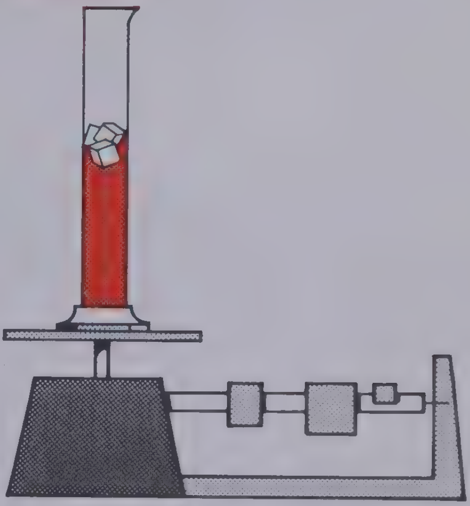
We do not have to worry about any ice already floating in the oceans. If it happens to melt, it would not cause the sea level to

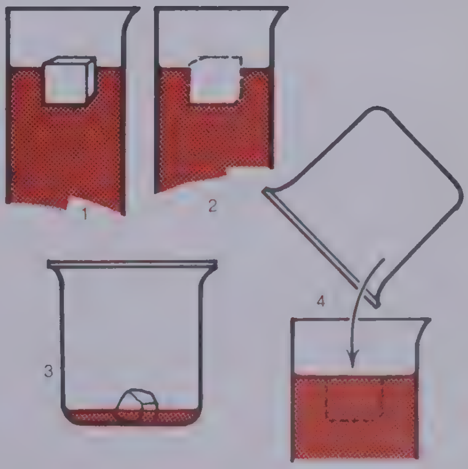
The amount of heat needed to melt 1 kg of a solid at its melting point is called the "latent heat of fusion", from the Latin word *latere* which means "to hide". Since adding this heat to a solid at its melting point causes no temperature increase, the heat seems to be hidden during the process of melting.

Latent Heat of Fusion for Some Common Substances (in kJ/kg)

water	335	wax	147
aluminum	322	lead	24.7
copper	176	mercury	11.7
iron	105		

Note: 1 kJ/kg = 1 J/g





rise. Most of the world's supply of fresh water is trapped on land, in the giant glaciers covering Greenland and Antarctica. If these glaciers should ever melt, we would then be in trouble. Think of the following statistics and what they would mean:

Surface area of Earth = 510 000 000 000 000 m^2
Volume of ice on land = 491 000 000 000 000 m^3

Calculate the depth to which this water would cover the Earth if it melted. It's easier if you assume the Earth is flat.

6.6 Investigation: Heat / Melting

PROBLEM: HOW DOES HEAT AFFECT THE MELTING OF ICE?

MATERIALS:

250 ml beaker
supply of crushed ice or snow
thermometer

PROCEDURE:

Fill a 250 ml beaker about one-third full of crushed ice or snow. Measure its temperature as it melts and then continue to measure for about five minutes more. Stir steadily to ensure that the whole mixture is at the same temperature. Record the temperature, in a table, every minute, and then draw a graph of temperature versus time.

QUESTIONS:

1. Does the ice absorb heat or release heat as it melts?
2. Where does the heat needed to melt the ice come from?
3. Where does the heat go, as the ice melts?
4. When the snow is partially melted, the water is at the same temperature as the snow. Why doesn't it start warming up to room temperature, before the rest of the snow melts?
5. What is the melting temperature of ice? What is the freezing temperature of water?
6. If you see a pond of water with some ice floating around on it, what will the temperature of the water be?
7. What must happen before the temperature of the pond can fall below the freezing point?

If you start with very cold ice, its temperature increases until it reaches 0°C. As the ice begins to melt the temperature will not increase, but will remain at 0°C. Gradually all of the ice melts. Only then can the temperature begin to rise again. While the ice is melting heat is being absorbed, but the temperature does not increase.

Try to imagine what would happen if ice and snow melted as soon as their temperature warmed up to 0°C, or froze when their temperature fell to 0°C. Winter streets would be ice-covered one moment, wet the next, and then frozen again, if the temperature varied even one degree. Snow would melt on the first sunny day,

Water has a greater latent heat of fusion than most other common solids, and as a result is an excellent refrigerant. To melt each gram of ice in a cooler would require 335 J of heat which the ice will absorb from the surrounding food. A substance with a lower latent heat of fusion would not absorb as much heat from the food as it melts, and hence would not have as great a cooling effect.

And, when 1 g of water freezes, an equal amount of heat is released, so that, due to its large latent heat of fusion, water has a significant effect on climate. The heat released when large lakes freeze is sufficient to keep the temperature of surrounding land masses several degrees above other regions at the same latitude but with no adjacent bodies of water. Because of the Great Lakes, southern Ontario has much milder winters than regions at the same latitude on the Prairies.

When rock salt is scattered on ice, the warmer rock salt immediately melts some ice and dissolves in the water to form a salt water solution. This solution has a lower freezing point than pure water and as a result does not re-freeze. The process continues until all of the salt has dissolved or all of the ice has melted.

One way of achieving a temperature below 0°C is to mix some water, crushed ice and salt. This technique was used in the days of making homemade ice cream. Why not try it?

The amount of heat required to completely vaporize 1 kg of a liquid at its boiling point is called its latent heat of vaporization.

Latent Heat of Vaporization of Some Common Liquids (in kJ/kg)

water	2260	oxygen	213
ethyl alcohol	854	helium	25
mercury	297		

Note: 1 kJ/kg = 1 J/g

The high heat of vaporization of water has many significant applications. Steam heating is far more efficient than hot water heating. One gram of steam condensing in a radiator and then cooling to room temperature can release about 2574 J of heat, whereas 1 g of boiling water in the same radiator can only release about 539 J of heat while cooling to room temperature.

as would outdoor skating rinks, ending skiing and skating until the next snowfall and freezing day. An ice cube dropped into a glass of pop would melt instantly, without cooling the pop at all. A person trying to cross a frozen lake would probably fall through the ice immediately. It would be melted by the heat from his boots.

Fortunately, it does take extra heat to melt ice, and to boil water as well. As you do the next investigation, remember that it takes 420 J of heat to heat 1 g of water from 0°C to 100°C. Compare this result with the amount of heat needed to melt 1 g of ice.

6.7 Investigation: Melting Ice

PROBLEM: HOW MUCH HEAT IS NEEDED TO MELT ONE GRAM OF ICE?

MATERIALS:

styrofoam cup and supply of ice cubes
equal-arm balance
thermometer

Every gram of water which evaporates from the soil or from a body of water absorbs 2260 J of heat. As a result, temperatures remain lower on hot sunny days by evaporation of water. Also, every gram of water vapor which condenses from the atmosphere releases 2260 J of heat. Thus rainy, foggy or even snowy days are often quite warm, due to heat released into the atmosphere by condensing water vapor.

PROCEDURE:

Measure the mass of a styrofoam cup and then fill it three-quarters full of hot water from the tap. Measure the mass of the cup and contents. Measure the starting temperature carefully, and then drop in a medium-sized ice cube. After all of the ice has melted, measure the final temperature of the water, and again measure the mass of the cup and its contents. Calculate the amount of heat needed to melt 1 g of ice by following the sample given below:

OBSERVATIONS:

Be sure to include the following data:

While the ice is melting, cover the styrofoam cup with a tight-fitting lid. Can you explain how this will improve your results?

	OUR RESULTS
mass of the styrofoam cup	5.1 g
mass of the cup + hot water	96.7 g
mass of the hot water	96.7 – 5.1 = 91.6 g
the mass of the cup, water and ice cube	135.4 g
mass of the ice cube	135.4 – 96.7 = 38.7 g
temperature of the hot water	85°C
temperature after melting	36°C
temperature change during melting	85 – 36 = 49°C
Calculate the heat lost by the hot water,	0.0916 × 49 × 4.2 = 18.85 kJ
the heat gained by the ice water (after melting),	0.0387 × 36 × 4.2 = 5.85 kJ
the heat used to melt the ice	18.85-5.85 = 13 kJ = 13 000 J
and the heat used to melt 1 g of ice.	13 000/38.7 = 336 J

QUESTIONS:

1. How much heat is required to melt 1 g of ice? How much heat would be required to melt 1 kg of ice?
2. What did we assume was the temperature of the ice cube just prior to dropping it into the hot water? Is this necessarily true?

6.8 The Melting and Freezing of a Solution

Car engines are cooled by water flowing through the engine and the radiator. If this water froze, it would expand and crack open the engine block. In the winter, something must be done to keep the water from freezing. We add antifreeze, but what does it do? How can you stop water from freezing when the temperature drops below its freezing point?

6.9 Investigation: Antifreeze / Melting Point

PROBLEM: WHAT IS THE EFFECT OF ANTIFREEZE ON THE MELTING POINT OF ICE?

MATERIALS:

250 ml beaker
antifreeze
supply of crushed ice

PROCEDURE:

Fill a 250 ml beaker half full of crushed ice or snow. Add antifreeze, 25 ml at a time, mixing thoroughly and measuring the temperature of each mixture. Stop when all the snow has melted. Record your data in a chart.

Be sure to report the melting temperature for each of the five samples.

QUESTIONS:

1. How can the temperature fall if room-temperature antifreeze is added? Where does this heat go?
2. Does adding more antifreeze raise or lower the freezing point?
3. If you place a mixture of antifreeze and water in a refrigerator at 0°C, will the mixture freeze?
4. Why is antifreeze called antifreeze?

6.10 Heat, Temperature and Boiling

We found that it takes about 336 J of heat to melt 1 g of ice and change it to water. Once melted, another 336 J of heat would raise the water temperature by 80°C, even though during melting the temperature does not rise by one degree. The heat added must be used for something else.

During melting, water particles are separated from each other and can move around more freely in the liquid state. The distance between the particles does not change very much.

During boiling, the particles move much further apart. The particles in steam are far enough apart to make the steam invisible. Does this require more heat than melting?

To compare the heat needed for melting with the heat needed for boiling, we are going to start with some ice in a test tube. By heating it steadily, and timing the changes of state which occur, we can compare the amount of heat required to bring about each change of state.

It requires about six or seven times as much heat to vaporize 1 g of water as it does to melt 1 g of ice.

6.11 Investigation: Boiling / Melting

PROBLEM: IS IT MORE DIFFICULT TO BOIL WATER INTO STEAM THAN TO MELT ICE INTO WATER?

MATERIALS:

test tube
Bunsen burner
supply of ice cubes

PROCEDURE:

Put several pieces of ice cubes in a test tube. Hold the test tube in a Bunsen burner flame and begin timing. Watch the contents of the test tube carefully, moving it gently back and forth in the flame. Record the elapsed time when melting begins, when melting is complete, when boiling first begins and when the water has completely boiled away. *Stop heating as soon as the water has boiled away.*

QUESTIONS:

1. In which change of state does the greatest volume change take place, melting or boiling?
2. Which change of state requires the most heat, melting or boiling?
3. Based on the comparison of the time required to melt the ice and the time required to boil the water, estimate how much heat would be required to boil 1 g of water. (Recall that it takes 336 J to melt 1 g of ice)
4. If ice, water or steam are all made of the same particles, then in which change of state does the distance between the particles change the most, boiling or melting?
5. What does the heat do, during a change of state?

6.12 The Boiling Point of a Solution

Ethylene glycol antifreeze lowers the freezing point of water to which it is added. A solution of antifreeze and water can have an extremely low freezing point in spite of the fact that pure ethylene glycol freezes at only –17°C. How can this be?

According to our particle model for matter, solids form when the particles of a liquid stick together. Something about the antifreeze particles makes it more difficult for the water particles to stick together, and vice versa.

What do you think would happen if you added antifreeze to boiling water? Will it raise the boiling point by making the water particles stick together, or lower the boiling point by making it easier for the water particles to break apart and form steam?

Is it better to leave the antifreeze-water solution in your car year-round, or should you replace it with pure water during the summer months, when there is no danger of freezing?

6.13 Investigation: Antifreeze / Boiling Point

PROBLEM: WHAT IS THE EFFECT OF ANTIFREEZE ON THE BOILING POINT OF WATER?

MATERIALS:

250 ml beaker	antifreeze
thermometer	Bunsen burner

PROCEDURE:

Boil various mixtures of water and antifreeze. Measure and record the temperature at which each mixture boils.

Record the boiling temperatures in °C for the following: 100 ml water and 0 ml antifreeze; 90 ml water and 10 ml antifreeze; 80 ml water and 20 ml antifreeze; 70 ml water and 30 ml antifreeze.

Density and Antifreeze

Water freezes at 0°C and ethylene glycol antifreeze at –17°C. A mixture of 50% water and 50% antifreeze does not freeze until the temperature falls to –37°C. Can you explain that?

The density of water is 1000 kg/m^3 and of ethylene glycol, 1156 kg/m^3. The density of a solution of the two should be somewhere in between. A hydrometer, similar to a battery hydrometer, but with a different scale, can be used to measure its density. We know how to calculate the density if we need to.

QUESTIONS:

1. Does antifreeze have the same effect on the boiling point of water as it does on the freezing point of water?
2. What effect does increasing the concentration of antifreeze have on the boiling point?
3. Does the presence of antifreeze seem to help or hinder the change from water to steam?
4. Does the presence of antifreeze seem to help or hinder the change from ice to water?

6.14 What Is Steam?

Heating a test tube of water vigorously enough will produce steam. Bubbles appear in the water and a cloud of white mist can be seen at the mouth of the test tube. The mist is not really steam, but consists of tiny water droplets which have formed from the steam as it comes in contact with the cooler air and condenses. Real steam is invisible. Can you see anything inside the bubbles in the water or in the space just above the water? We should be able to show that steam is water that has been changed to its gaseous form.

Which produces a more severe burn, steam or boiling water? Why?

6.15 Investigation: Boiling and Condensing / Volume Changes

PROBLEM: DO VOLUME CHANGES TAKE PLACE DURING BOILING AND CONDENSING?

MATERIALS:

250 ml beaker
safety goggles
test tube

In a steam heating system, the return pipes are much smaller than those which carry the steam from the boiler. Why is this possible?

PROCEDURE:

Heat 3 or 4 ml of water in a test tube until it is boiling freely. Quickly turn it upside down into a beaker of cold water. Watch carefully as the hot test tube and its contents cool. Try it again, but without heating the water. Mark the water level in each tube.

DANGER:

Wear safety goggles. Do not point a test tube of boiling liquid at anyone.

QUESTIONS:

1. Why should you perform the experiment over again with cold water?
2. What is there in the cool test tube that keeps the water from rising up into it?
3. What is in the space above the boiling water?
4. What is in the bubbles in the boiling water?
5. When steam changes to water, is there a change in volume? What must happen?
6. If steam and water are both made of the same type of tiny particle, what is the difference between them?

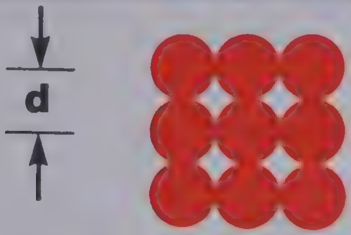
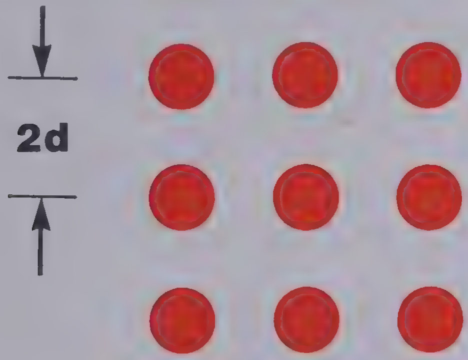
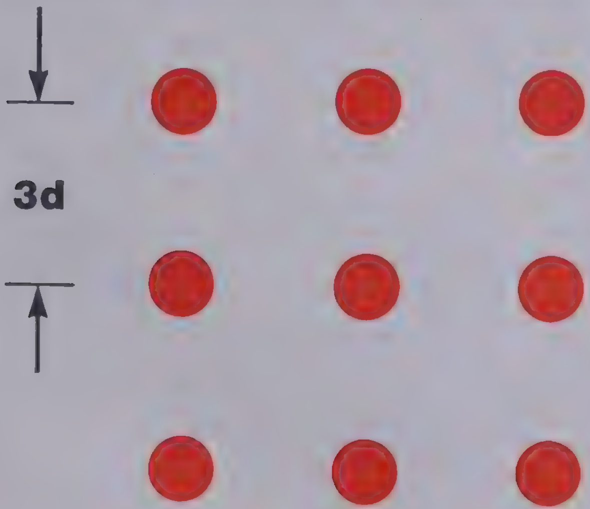
6.16 Exercise: Estimating Particle Spacing

Ice, water and steam can be changed from one to the other by the addition or subtraction of heat. The changes produced by heat are temporary, and may be reversed. This change is called a physical change. According to our particle theory, the particles in all three states are identical. They may be stuck together, or free to move closer together or farther apart, but they are still the same particles.

To form steam, our theory suggests that they must be separated a very great distance from each other.

To be able to determine the distance between water particles in a cloud of steam, we need some information. We also need to make some approximations and assumptions. One millilitre of water expands during boiling to make about 1700 ml of hot steam. Let us then assume that the particles in water are right next to each other, like the particles in the diagram. Notice that, when they touch, the distance between them, measured center to center, is just the diameter of the particle. If the distance between particles is increased to 2d (from d) then the water fills a space twice as long, twice as wide and twice as high. This is eight times the original volume. Do you see why?

You should be able to figure out what happens when the space between particles is 3d, 4d, 5d and so on. Make a chart, continuing until the steam has a volume of at least 1700 ml.

	Particle Spacing	Volume of Each Particle	Total Volume
	d	d^3	1 ml
	2d	$8d^3$	8 ml
	3d	$27d^3$	27 ml

6.17 A Question about Steam

If the particles are so far apart in steam, what keeps them apart? What keeps them together? Why don't they come back together? Do they just hang freely in space, unsupported? What about the effects of gravity? Why don't the particles in steam fall down to the bottom of their container?

Start thinking about this question now. We will try to answer it more completely in Chapter Seven.

6.18 Boiling under Reduced Pressure

The boiling point of water is not constant. It changes from day to day.

To boil, the particles of a liquid must move very far apart and escape through the surface of the liquid to become gas particles. Is there anything above the surface of the liquid pushing back on these particles as they try to escape? Of course there is the atmosphere, a layer of gas particles approximately 120 km thick, on top of the liquid surface, hindering the escape of liquid particles into the gaseous state. Meteorologists call this air pressure. Due to existing weather conditions, air pressure may vary from day to day. Could these changes in air pressure above the liquid be the reason for the change in boiling point? What would you expect to happen to the boiling point of a liquid on a day when the air pressure was very low? Or very high?

Effect of Elevation on Atmospheric Pressure and the Boiling Point of Pure Water

Elevation (in m)	*Atmospheric Pressure (as [illegible] % of sea level)*	*Boiling Point of Water (in °C)*
0	100	100
286	96.7	99
580	93.3	98
883	90.0	97

We can easily investigate this question. Although we cannot alter the existing air pressure much, we can boil a liquid in such a way that air pressure above the liquid is reduced.

6.19 Investigation: Boiling Point / Reduced Pressure

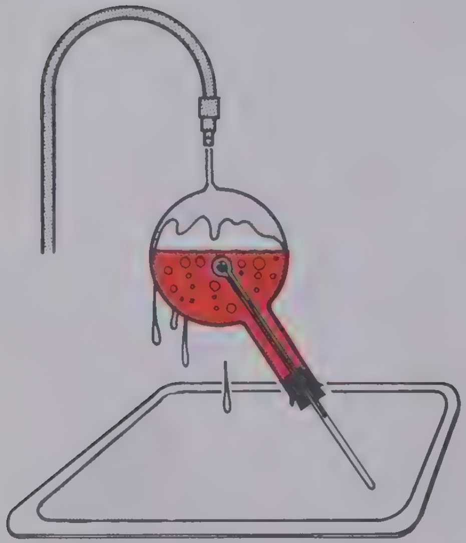
PROBLEM: WHAT IS THE EFFECT OF REDUCED PRESSURE ON THE BOILING POINT OF WATER?

MATERIALS:

250 ml boiling flask	retort stand
1-hole stopper with thermometer, to fit flask	ring clamp
Bunsen burner	

PROCEDURE:

Put 150 ml of tap water into the boiling flask and bring it to a vigorous boil. Remove the flask from the heat and quickly insert the stopper into the mouth of the flask. *Be very careful not to burn your hands.* Once this has been done, invert the flask and gently run cold water from the tap over its bottom. Observe both the activity within the flask and the temperature of the water within the flask. Continue until the water in the flask no longer appears to be boiling.



QUESTIONS:

1. What was the lowest temperature of the water in your inverted flask when boiling occurred?
2. Just before the flask was plugged, what occupied most of the space above the boiling water in the flask?
3. As the sealed flask was cooled, what change of state was occurring in the space above the water?
4. Why was there less pressure on the liquid in the inverted flask than there was when the flask was upright and open?
5. Where on the surface of the Earth would the atmospheric pressure be constantly lower than normal? As a result, what precautions would have to be taken in boiling food at these locations?
6. What would be the opposite effect? That is, what would we expect increased pressure to do to the normal boiling point of a liquid? Can you think of any everyday examples of boiling a liquid under increased pressure, or increasing the pressure on a liquid to keep it from boiling?

Normal atmospheric pressure can be strong enough to crush the sides of a completely empty can. Ask your teacher to perform this demonstration for you.

6.20 Sublimation

If changes of state can occur when heat causes the particles of matter to move farther apart, then perhaps the particles of a solid could change directly to a gas, without first changing to a liquid.

A frost-free refrigerator uses this idea. Any ice which forms in the refrigerator is carried away by currents of cold air circulating inside the freezer. The ice and frost change directly to water vapor without changing to a liquid first.

In our next investigation, iodine crystals are heated to form iodine vapor, which is then cooled to form iodine crystals again. In neither case is any liquid evident. This process is very similar to the formation of snow crystals and frost on the inside of windows.

If wet clothes are hung out to dry on a cold winter day when the temperature is below 0°C, the water in the clothes quickly freezes. Later, however, the same clothes will be totally dry. What change of state has occurred as the clothes dried? Why would it be impossible for liquid water to have appeared in the drying process?

Mothballs are made of solid napthalene, but when placed in clothing and other materials which are being stored, they sublime into napthalene vapor which acts as a deterrent to moths.

6.21 Investigation: Solid to Gas

PROBLEM: CAN A SOLID CHANGE DIRECTLY TO A GAS?

MATERIALS:

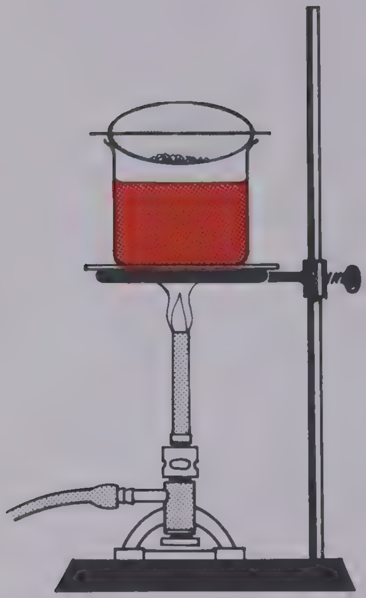
250 ml beaker
2 watch glasses
Bunsen burner
retort stand
ring clamp
filter paper
iodine crystals

PROCEDURE:

Set up the hot water bath as in the diagram and place a watch glass on top of the 250 ml beaker. Sprinkle a few iodine crystals in the watch glass, and cover it with a filter paper and another watch glass. Heat the water gently and carefully observe the iodine crystals and the watch glass. Do you see any evidence of liquid iodine? Do you see any evidence of iodine vapor or gas? How many changes of state took place in your experiment?

QUESTIONS:

1. The change of state which takes place between a solid and a gas without the appearance of a liquid is called sublimation. What would happen if ice sublimed?
2. There are three states of matter. How many changes of state are possible?
3. Using our particle model for matter, devise a suitable explanation for the process of sublimation. Can you do the same for all changes of state?



The substance we know as dry ice is really nothing more than the solid form of the gas carbon dioxide. Its freezing point is very low (–78°C), so that when a piece of solid carbon dioxide is exposed to room temperature, it sublimes into carbon dioxide gas. Why is it called "dry" ice? Why would dry ice be superior to normal ice as a refrigerant?

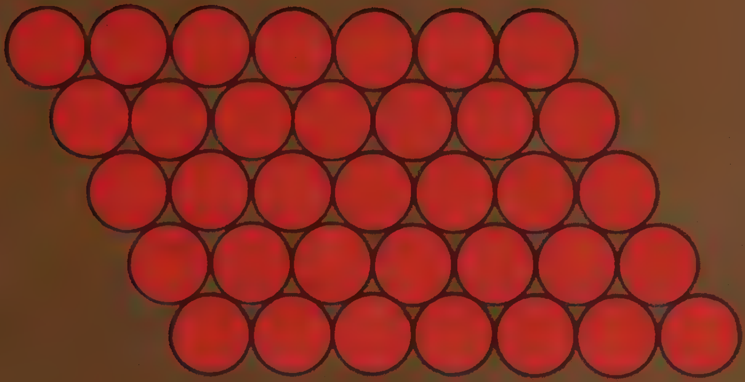
We have reached the point where we must try to combine what we know about the structure of matter with what we know about the nature of heat.

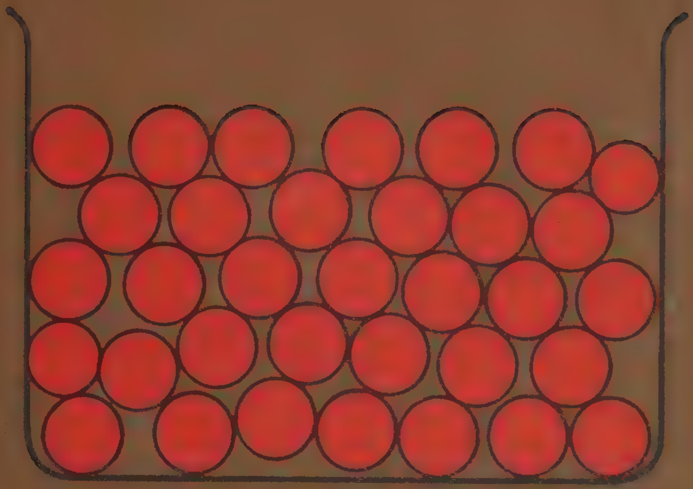
6.22 Solids, Liquids and Gases: Some Possible Answers

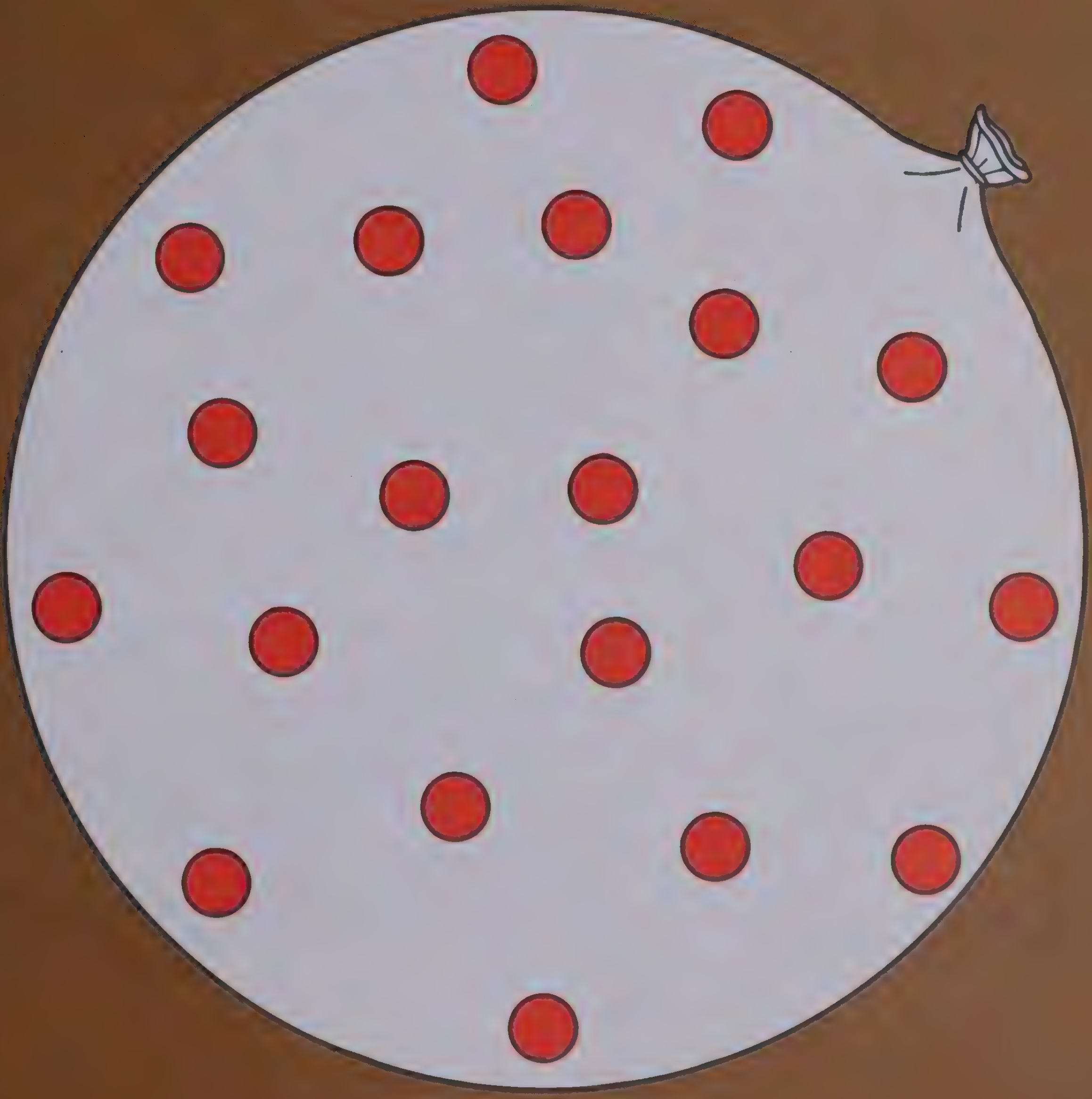
Q. What is a solid?
A. Particles joined together, often in regular patterns, to form regular rigid shapes.
Q. What is a liquid?
A. The same particles, but not attached as strongly together, so that they may flow easily when poured.
Q. What is a gas?
A. Again, the same particles, but in a much larger volume, and often spaced so far apart that the gas is invisible.

Of course, the questions above are answered according to a certain theory. A theory is only useful as long as it explains what we can observe. In the theory used above, the particles are always supposed to be the same. What observations does this explain about the changes of state?

1. Which state of matter should ordinarily be the most dense? Why?
2. Which state of matter should be the least dense? Why?
3. What does the heat do during boiling? Sublimation? Melting?
4. When water freezes, should it absorb heat or release heat?
5. When ice melts, should it absorb heat or release heat?







6.23 Summary

1. Heat, absorbed or given off, can cause matter to change from one state to another, as below:

CHANGE	COMMON NAME	HEAT TRANSFER
gas to solid	sublimation	released
gas to liquid	condensation	released
liquid to solid	freezing	released
liquid to gas	boiling	absorbed
solid to liquid	melting	absorbed
solid to gas	sublimation	absorbed

2. When ice melts, the temperature remains constant at 0°C, no change in mass occurs, a slight decrease in volume is evident and about 336 J of heat are absorbed to melt 1 g of ice.

3. The melting point of a solution is lower than the melting point of pure water.

4. Water boils at approximately 100°C and it requires about seven times as much heat to boil 1 g of water as to melt 1 g of ice. The steam produced occupies about 1700 times the volume of the water before it was boiled.

The degree of attachment of one particle to another depends on the *forces* holding them together. We will learn more about forces in Chapter Eight.

5. The boiling point of a solution is higher than the boiling point of pure water.

6. The difference between solids, liquids and gases may be thought of in terms of particle spacing and degree of attachment of one particle to another, as below:

STATE	RELATIVE PARTICLE SPACING	DEGREE OF ATTACHMENT
solid	close together	strong attachment
liquid	slightly further apart	much weaker attachment
gas	very much further apart	almost no attachment

7. The boiling point of a liquid is lowered by reducing the pressure above the surface of the liquid.

6.24 Further Investigations

1. Increased pressure can affect the melting point of a solid in much the same way as decreased pressure changes the boiling point of a liquid. Make a large block of ice by filling a cardboard milk carton with water and placing it in the freezer overnight. Remove the ice from the freezer about half an hour before the experiment is to be done to allow it to reach its melting temperature. Raise both ends of the ice well off the lab table and then loop a piece of very fine wire over

the ice. Attach heavy masses to each end of the wire. Observe the wire for about ten minutes. What happens to the ice on the bottom side of the wire? What happens on the top side of the wire? This process is known as regelation. Can you explain its part in making a hockey player's skates slide smoothly over fresh ice?

2. Break a piece of dry ice into small pieces and insert several of these pieces into a deflated balloon. Tie the mouth of the balloon into a tight knot and observe. What process is occurring inside the balloon? What substance is causing the balloon to be inflated? Check with your teacher regarding a chemical test you could do to identify the substance inside the balloon.
3. Fill a small jar *completely* with water and fasten the lid tightly. Insert this jar into a larger empty bottle, tighten its top and place both in the freezer overnight. Explain what you observe the next day. Give several everyday examples of instances where we must guard against this outcome. Try the same experiment, using a liquid – antifreeze, for example – other than water. Your freezer must be able to go below –17°C to freeze pure antifreeze. If it cannot, try using dry ice.
4. Boiling a liquid under reduced pressure may also be demonstrated using a vacuum pump and bell jar. Fill a 250 ml beaker with hot tap water and place a thermometer in the beaker. Put this beaker and a watch glass with some calcium chloride crystals on it on the vacuum pump plate under the bell jar, and make sure that a good seal has been made. Turn on the vacuum pump for a few minutes and observe the water. Take note of the temperature of the water. See if you can find out why the calcium chloride crystals were added. Repeat the experiment using other liquids at room temperature.

When a liquid is boiled under increased pressure, the reverse occurs – the boiling point increases. Temperatures higher than 100°C may be achieved by boiling water only if the pressure above the surface of the water is increased. Pressure cookers and sterilizers make use of this phenomenon to achieve water temperatures in excess of 100°C for faster and more thorough cooking, and elimination of bacteria which could survive normal boiling temperature of 100°C. The water-antifreeze mixture in an automobile radiator and cooling system is kept under increased pressure to avoid boiling, even when engine temperature exceeds 100°C. What do you suppose happens when you see a car with its radiator boiling over?

Calcium chloride is very deliquescent that is, it has the ability to dissolve itself in moisture taken from the air. Can you see why these crystals were placed under the bell jar? Examine them closely after the experiment is over

6.25 Review

1. Name the six changes of state and give an everyday example of the occurrence of each.
2. A piece of ice initially at –20°C is heated steadily until it has melted, begun to boil and completely boiled away. Sketch a temperature versus time graph for this entire process and identify the significant features of the graph.
3. 2100 J of heat is supplied to an ice cube which has a mass of 5 g and is initially just at 0°C.
   (a) How much of this heat is needed to melt the ice cube?
   (b) How much heat is left to warm up the melted water?
   (c) What will be the final temperature of this water?

(d) How much heat would have to be absorbed in order to freeze this water, starting from the temperature calculated in (c)?

4. Why is an antifreeze-water mixture used in car engines? Why would 100% pure antifreeze be ineffective?
5. Why should it take much more heat to boil 1 g of water into steam than it takes to melt 1 g of ice into water?
6. Explain how sublimation is involved when clothes are hung out to dry on a windy day and the temperature is well below freezing.

6.26 Instructional Objectives

Before modern heating systems were available, it was common practice to put a large tub of water in the fruit cellar with the stored fruits and vegetables. On cold nights, the water would freeze, thereby releasing large quantities of heat (336 J/g) to the surroundings, and keeping the fruits and vegetables from freezing.

1. To name the changes of state and describe whether heat is absorbed or given off in each.

2. To describe the process of melting, in terms of volume change, mass change, temperature change, heat exchange, effect of dissolved solutes and particle rearrangement during the time when melting is occurring.

3. To perform an experiment, collect data and calculate the amount of heat necessary to melt 1 g of ice.

4. To describe the effect of antifreeze on the freezing point of water and to account for any differences due to concentration of the mixture.

5. To estimate the approximate amount of heat necessary to boil 1 g of water.

6. To describe the effect of antifreeze on the boiling point of water and to account for the heat needed to boil a liquid.

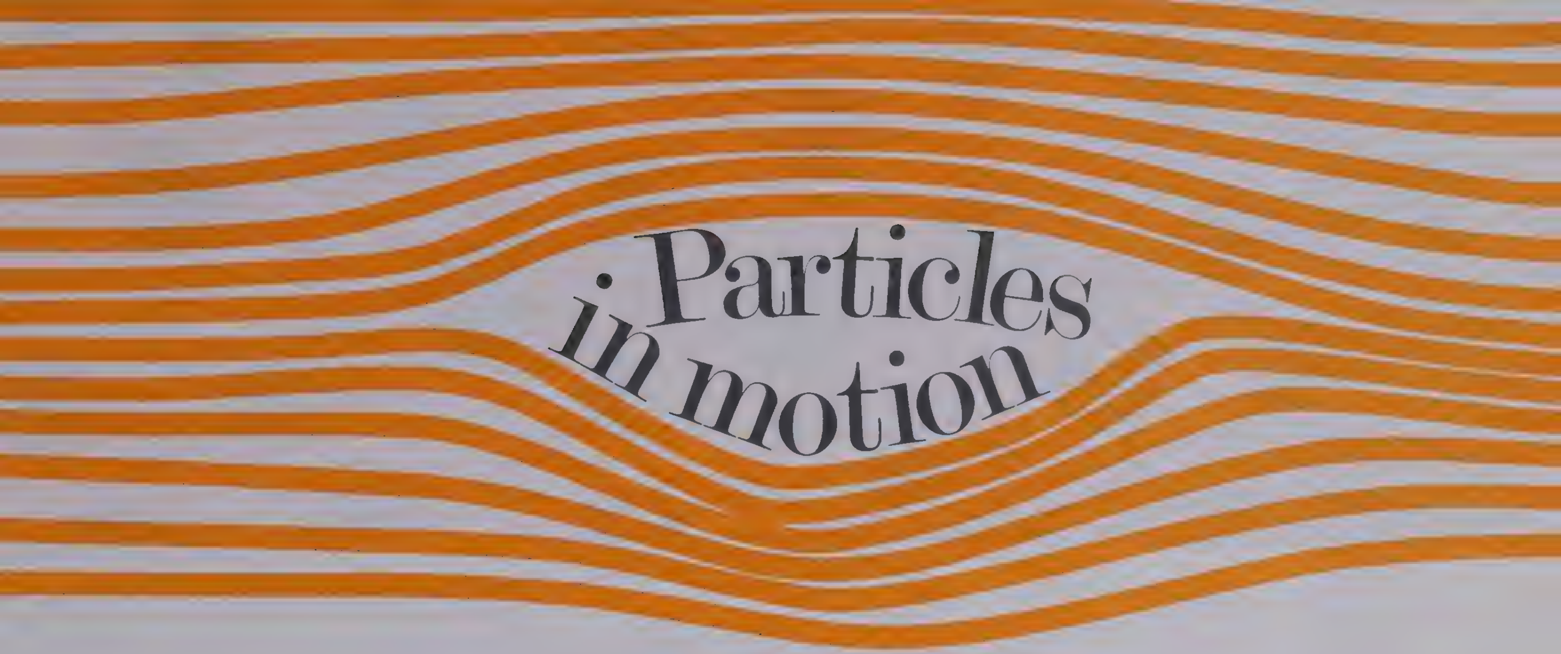
7. To describe the volume changes which take place during boiling, and as a result, to be able to estimate particle spacing in steam as compared to water.

8. To describe and account for the effect of reduced pressure on the boiling point of water.

9. To describe the three states of matter in terms of particle spacing and degree of particle attachment; and to account for the role of heat in changing both of the above, when matter changes state.

6.27 Glossary

air pressure
antifreeze
approximation
assumption
boil
change of state
condensation
evaporate
freeze
fusion
liquifaction
melt
meteorologist
pressure
regelation
solidification
steam
sublimation



Particles in motion

7.1 The Nature of Heat: Two theories
7.2 Kinetic Models
7.3 Investigation: Particle Collisions
7.4 Paper Chromatography
7.5 Investigation: Particle Motion / Paper Chromatography
7.6 Particle Motion and Dissolving
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7.10 Volume of a Gas: Colliding Particles
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7.14 Motion of Smoke Particles: Brownian Motion
7.15 Investigation: Particle Motion / Smoke in Air
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7.1 The Nature of Heat: Two Theories

We have developed a model which we are trying to use to explain the structure of all matter. We have said that all matter is composed of particles, so tiny that we cannot see them, even under a microscope. But how does our study of heat in the last two chapters fit into this model? How can we explain what we have learned about heat, temperature and changes of state based on our particle model of matter? What effect does heat have on these particles, of which all solids, liquids and gases are composed? In simpler terms, what is heat?

Let's look back at some of the results of investigations we have done which involve heat:

1. When heat is added to a substance, the substance expands. This can only be explained if heat somehow causes the particles to move farther apart.
2. Dense metals with heavy, tightly packed particles cannot hold heat as well as less dense substances whose particles are lighter and more loosely packed. Heat must have something to do with how much room the particles of a substance have around them.
3. Solids dissolve faster and to a greater degree in hot liquids than they do in cold liquids. The particles of a solid break off and move among the liquid particles faster and more easily when the liquid is hot. Adding heat to a liquid seems to create more and larger spaces between the liquid particles which can be occupied by more dissolved solid particles.
4. When hot and cold substances come into contact or are mixed, they "share" their heat. Heat can leave a hot substance and enter a cold substance until the temperature of each is the same.
5. When heat is added to a solid such as ice, in which the particles are held tightly in a rigid pattern, the particles "come loose" and form a liquid in which they are much freer to move.
6. Similarly, when heat is added to a liquid, the particles move much farther apart and seem to become almost totally free of each other as they form a gas.

Another name for the particle motion theory is the kinetic molecular theory. By the end of Chapter Eleven you will see the connection between the two names.

Can you see any clue? Do any of these examples have some concept in common? Early scientists who were interested in determining the nature of heat were looking for exactly the same clue, which for many years eluded them. It appears to us that heat must have something to do with the motion of the particles of which all matter is composed. The addition of heat seems to make the particles move faster. Before our early scientists were able to see this connection between heat and particle motion, a theory of heat had developed, called the caloric fluid theory, which eventually gave way to the moving particle approach, the particle motion theory.

CALORIC FLUID THEORY

Prior to the beginning of the nineteenth century, most important scientists believed in the caloric fluid theory. According to this theory, heat was assumed to be a substance which flowed into objects as they heated up and flowed out of objects as they cooled down. It also flowed from hot objects into cold objects until their temperatures were equal.

The supply of caloric fluid in an object must either be limitless, or caloric fluid must be created when an object is rubbed

There were, however, several drawbacks to the caloric fluid theory. If heat were a substance, then it should have mass and occupy space. Thus, a hot object should be larger and have a larger mass than when it was cold. In fact, although hot objects are slightly larger, they have been shown to have the same mass as when they are cold. Also, when two objects are rubbed together, they both become hotter. Where does this extra caloric fluid come from?

PARTICLE MOTION THEORY

An alternative to the caloric fluid theory was proposed as early as the seventeenth century by Galileo and, later, by Francis Bacon. His idea was that heat, in fact, was nothing more than the motion of the particles of which all matter is composed. Although this theory was not immediately accepted, additional experimental evidence was provided by Benjamin Thompson in 1798 and by Sir Humphrey Davy at about the same time. Finally, in the early nineteenth century, the modern theory of heat, the particle motion theory, was formulated by James Clerk Maxwell. According to this theory, all matter is composed of particles which are continuously in motion. At a particular temperature, all particles of a substance are moving at approximately the same speed, but when heat is added, these particles speed up and this increased particle motion results in a higher temperature.

Sir Humphrey Davy was able to melt ice by rubbing two pieces of it together. This completely confused the caloric-fluid believers, since even they agreed that it takes extra caloric fluid to melt ice. Where could this extra have come from?

Maxwell published his theories of heat in two books entitled *Theory of Heat* (1871) and *Matter and Motion* (1876).

Perhaps the best way to compare the merits of the two theories would be to examine the explanation each theory would provide for some of the properties of heat which we have already investigated.

PROPERTY	CALORIC FLUID THEORY	PARTICLE MOTION THEORY
Temperature	A measure of the amount of caloric fluid which accumulates around each particle of a substance.	A measure of the average amount of motion of the particles of a substance.
Heat	The total amount of caloric fluid contained within a substance	The total amount of motion possessed by all of the particles of a substance
Thermal expansion	Caloric fluid flows into a substance when heated, thereby pushing all of the existing particles of a substance further apart. Thus they take up more space.	As the substance is heated its particles move faster and collide more violently and more often with their neighbors, thereby pushing them further apart. Thus they take up more space.
Transfer of heat	Caloric fluid is tightly packed around the particles of a hot substance and more loosely packed around the particles of a cooler substance. When these are mixed, caloric fluid flows from the hot to the cold until it is equally concentrated around all of the particles of the mixture.	When hot, fast moving particles are mixed with colder, slower moving particles, the fast particles are slowed down by collisions with the slow particles and vice versa, until all of the particles are moving at approximately the same speed.
Heat capacity	Dense materials consist of particles which are tightly packed, thereby allowing less room for caloric fluid to accumulate around the particles. Less dense substances have more room around each particle for caloric fluid to accumulate.	In dense materials, heavy and tightly packed particles cannot speed up as much when heated because of collisions with neighboring particles. In less dense materials the neighboring particles are lighter and further apart and particles may speed up more when heated in the absence of collisions with neighbors.
Melting	When heat is added to a solid, caloric fluid pushes the rigidly packed particles so far apart that they no longer exert strong forces on each other. As a result, they are less rigid and are free to move about more, which is characteristic of a liquid.	When heat is added to a solid, the particles speed up and move farther apart. This additional motion enables the particles to overcome the strong forces holding them rigidly in place, giving them the freedom of motion which is characteristic of a liquid.

How would we choose between these two theories of heat? Would it be possible for us to see the particles of a substance moving? Recall from your work on crystals that the particles of matter are so small that they are invisible, even under the most powerful microscope.

Can we still believe that these particles are moving without actually seeing them move? What we need, in order to strengthen our belief that the particles of a substance are moving, is some evidence based on laboratory investigations we have done. We will investigate some examples where the motion of particles is evident. How may these investigations affect our understanding of the structure of matter?

7.2 Kinetic Models

Before we begin to look for evidence that the particles of a substance are moving, let us look at some larger moving particles, to give us an idea of what to expect. If the particles of a substance are continuously moving, they are going to collide with each other. Our first investigation will enable us to observe collisions between moving marbles, to learn what to expect when particles collide.

If we think of particles as marbles, what is holding the marbles together to form solids and liquids?

7.3 Investigation: Particle Collisions

PROBLEM: WHAT CAN WE LEARN ABOUT PARTICLE COLLISIONS BY OBSERVING MARBLE COLLISIONS?

MATERIALS:

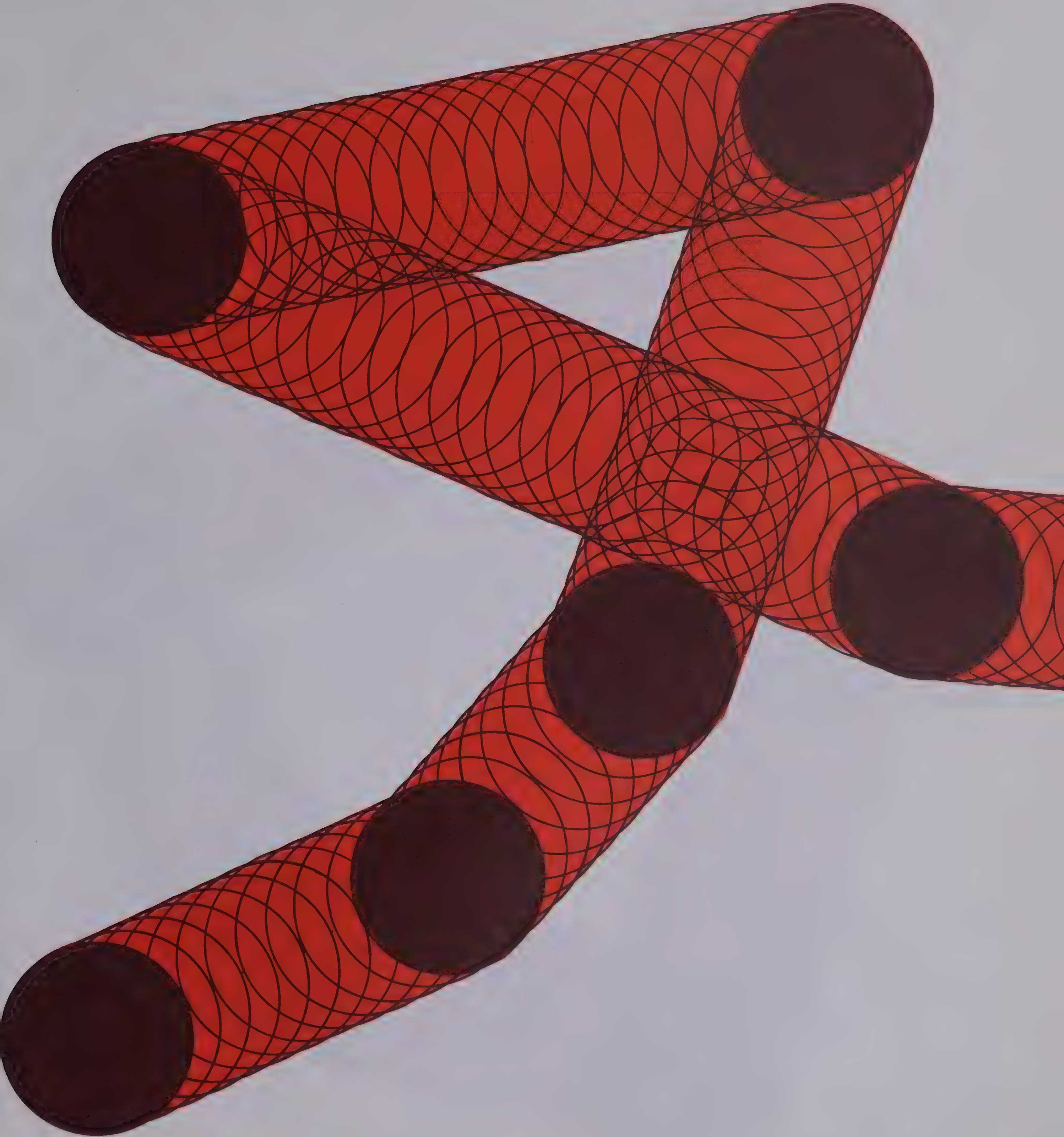
short length of "I" beam drapery track
24 small marbles and 3 large marbles
square cake tin

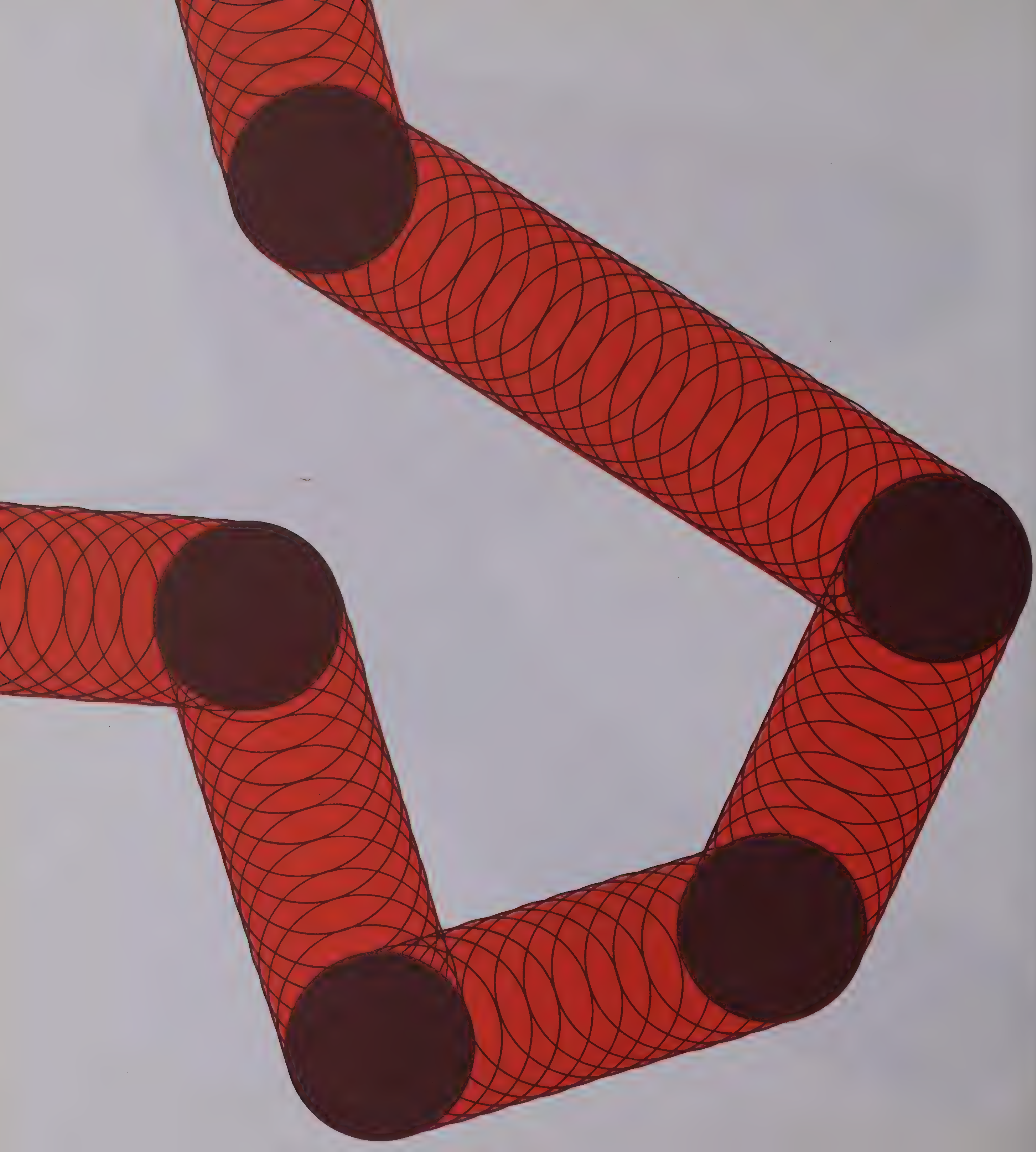
PROCEDURE:

Place one of the marbles on the track and send another down the track to hit it. Try various sizes of marbles and various speeds for the moving marble. Draw sketches to show what happens as a result of each collision. Next send one or more marbles down the track to hit a row of marbles. Again, try all combinations and speeds. Draw sketches of the results. Finally, put all of the marbles into a cake tin and shake it steadily back and forth, and from side to side. Watch one small marble for a period of time. What does it do between collisions? Try to draw a sketch showing the path taken by this small marble. On the average, which moves faster, a large or a small marble? Which moves farther between collisions?

QUESTIONS:

1. When does one of the target marbles move away faster than the speed at which it was hit?





2. When does a target marble move away slower than the speed at which it was hit?
3. When does the shooter marble (a) follow along or (b) bounce back, after the collision?
4. If a water particle collides with a sugar crystal, does this collision only cause the outer sugar particles to move? Explain, in terms of the results of your investigation.
5. If you hold a metal rod in a flame, you must soon let go. How can the end of the rod which is in your hand possibly get hot?
6. Do the marbles in the cake tin best represent a solid, a liquid or a gas? Explain.

7.4 Paper Chromatography

One of the simplest and best examples of particle motion may be observed when we use a blotter to soak up excess ink on a piece of paper. A wick in a kerosene lamp acts the same way. To begin with, the wick is dry, but when one end of the wick is placed in kerosene, the liquid particles move up the wick until some of them reach the top. When a match is touched to the top of the wick, the kerosene ignites. Why do kerosene particles move up the wick? Could something be pushing them? If so, what?

We can obtain a better understanding of this effect by placing some other, more visible, substance on the wick so that its particles move up the wick with the liquid particles. This idea forms the basis of paper chromatography, a technique which chemists and biologists often use to separate and identify the particles of which complex substances are composed.

In analyzing complex substances like amino acids and peptides (substances produced by the human body), biochemists have been able to use paper-chromatography techniques to separate and identify as many as sixteen different components

7.5 Investigation: Particle Motion / Paper Chromatography

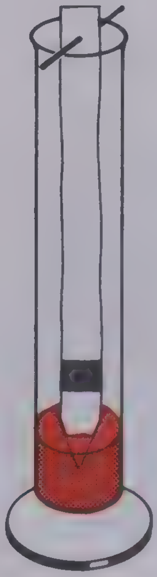
PROBLEM: WHAT CAN BE LEARNED ABOUT PARTICLE MOTION BY OBSERVING PAPER CHROMATOGRAPHY?

MATERIALS:

100 ml graduated cylinder
filter paper
black ink

PROCEDURE:

Cut a piece of filter paper into a long strip about 20 cm by 1 cm. At the bottom of this strip cut off the corners to make a point. Paint a wide strip of black ink across the filter paper about 2 or 3 cm above the point. Hang this strip of filter paper in a graduated cylinder so that just the point touches some water which is in the bottom of the cylinder. When the colors from the ink have moved up to within a few centimetres of the top of



the filter paper, remove it from the graduated cylinder and hang it up to dry.

QUESTIONS:

1. What caused the water particles in the graduated cylinder to move up the filter paper?
2. How many different substances can you identify on the filter paper strip? What factors may have caused each of these different substances to move up the filter paper a different amount?
3. What would happen if you cut out each colored section of the strip, dissolved the color in a small amount of water in a test tube, and then combined the liquids from each of the test tubes? Try it.
4. What difference would you have noticed if very hot water had been used in the graduated cylinder? Try it.

7.6 Particle Motion and Dissolving

In Chapter One we performed several investigations in which one substance, usually a solid, was dissolved in another substance, usually a liquid. At that time we probably failed to observe the dissolving process carefully enough to be able to detect any evidence of particle motion. In the investigation which follows, we will observe the dissolving process more carefully, in order to see some evidence of the motion of particles.

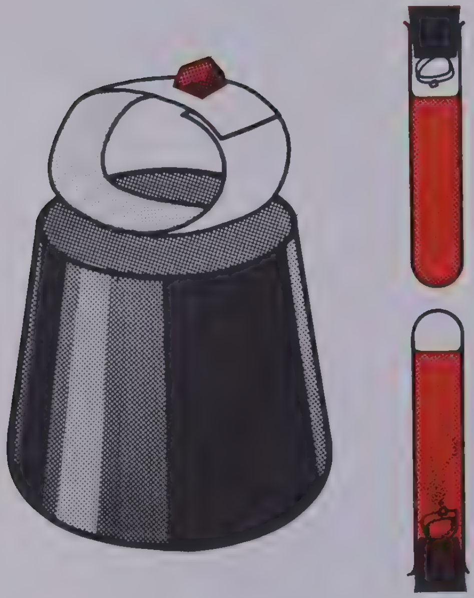
Why would some substances be insoluble, that is, incapable of dissolving when placed in a liquid?

7.7 Investigation: Particle Motion / Dissolving

PROBLEM: WHAT CAN WE LEARN ABOUT PARTICLE MOTION BY OBSERVING POTASSIUM PERMANGANATE AS IT DISSOLVES AND SPREADS OUT?

MATERIALS:

2 test tubes with stoppers
potassium permanganate crystals
masking tape



PROCEDURE:

Fill two test tubes to within 2 cm of their tops with water, one cold, and the other hot. Using inverted loops of masking tape, fasten one large crystal of potassium permanganate to the underside of each of the two stoppers. Insert the stoppers firmly into the test tubes so that the crystals are suspended just above the level of the water. Now slowly and gently invert each test tube and place them upside down where they will be undisturbed. Observe each closely for about five minutes, and then draw a sketch of each test tube.

QUESTIONS:

1. In which test tube did the potassium permanganate dissolve and spread out faster?

2. Why should the potassium permanganate dissolve and spread out at all, when it comes into contact with the water?
3. Why should it spread out faster in one test tube than in the other?
4. Why was the crystal introduced into the water as it was, rather than being dropped into the test tube?
5. How could we further increase the rate of dissolving and spreading out of the crystal?

7.8 Diffusion: The Motion of Gas Particles

What do we observe a short time after removing the cap from a bottle of perfume? What must have happened to cause the nerve endings in our noses to sense the presence of the perfume? Nothing can be seen coming from the open bottle toward our noses. Could it be that the perfume is giving off an invisible gas? If so, why does this gas spread out and eventually enter our noses? Perhaps the next investigation will help answer some of these questions.

This process of spreading out is called diffusion. Why should it be difficult to observe the particles of a gas as they diffuse? The investigation which we will do makes use of a clever technique to identify a moving gas, and tells us how far the gas particles have travelled, and also how fast.

Hydrochloric acid is a solution of hydrogen chloride gas in water and is manufactured by our bodies to aid in the digestion of food in the stomach. Have you ever heard of excess acidity?

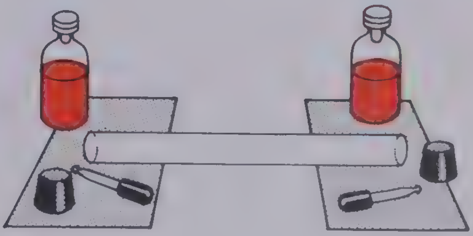
Ammonium hydroxide is a solution of the gas ammonia in water. It was first obtained during the middle ages by distilling the horns and hooves of the hart, and became known as "spirits of hartshorn". Today it is known as ammonia water and is used in household cleaning solutions, and to produce adipic acid and hexamethylene diamine, the main chemicals used in the manufacture of nylon.

7.9 Investigation: Particle / Gas Diffusion

PROBLEM: WHAT CAN WE LEARN ABOUT PARTICLE MOTION BY OBSERVING GAS DIFFUSION?

MATERIALS:

glass tube, 50 cm long, 2 cm in diameter
2 rubber stoppers to fit glass tube
concentrated hydrochloric acid
concentrated ammonium hydroxide
2 eyedroppers
metre stick
stopwatch



PROCEDURE:

Place the glass tube flat on the lab table, with a paper towel under each end. Remove the stopper from the bottle of hydrochloric acid. What do you observe? What must be coming from the hydrochloric acid for you to make that observation? Replace the stopper and make the same test with the bottle of ammonium hydroxide. Keeping these two bottles as far apart as possible, place one drop of hydrochloric acid in one end of the tube and one drop of ammonium hydroxide in the other end. Immediately replace the stoppers on the bottles of liquid, insert the stoppers in both ends of the tube, and start the

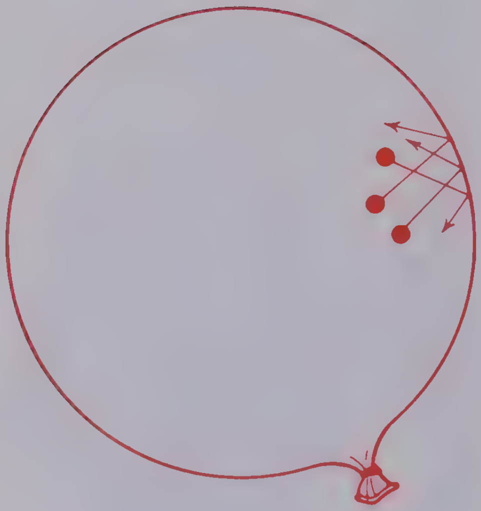
stopwatch. Observe the tube very carefully, noting when and where anything of significance occurs. Clean the tube thoroughly, by running water through it, and then dry it by pulling a paper towel through with a string. Repeat the same experiment, under the following conditions:

1. using a tube which has been cooled in ice
2. using a tube which has been heated in steam
3. using a tube which is tilted, first with the hydrochloric acid at the high end, then with the ammonium hydroxide at the high end

QUESTIONS:

1. What does the appearance of the white cloud of smoke indicate?
2. Which gas diffuses faster, the gas from the hydrochloric acid, or the gas from the ammonium hydroxide?
3. Why might one gas diffuse faster than the other? Why would the gaseous particles move at all?
4. What seems to be the relationship between the temperature of a gas and its diffusion rate? Can you explain why?
5. What do you think would happen if you could repeat the experiment using a tube with no air in it?

7.10 Volume of a Gas: Colliding Particles



If the particles of a gas are continually moving, then there must be collisions between them. If the gas particles are enclosed in a container, there must be a large number of collisions between the particles and the walls of the container. When a particle collides with a wall of the container, it pushes on the wall, and when a large number of these pushes occur almost simultaneously, we can say that the gas is exerting a "pressure" on the walls of the container. This is precisely the effect you are trying to create when you inflate automobile tires with a large number of air particles. What effect will temperature have on the pressure exerted by a gas? Will faster moving particles push harder on the container? Will they collide more often than slower moving particles?

If the walls of the container are flexible, what effect should this increased gas pressure have on the size of the container? Blow up a balloon and estimate its diameter. Now place the balloon in a freezer for a few minutes. What do you notice about its size? What would happen if the balloon were placed in a warm oven? Clearly, there is a relationship between the temperature of a gas and the volume of space the gas occupies.

In the investigation which follows, we will trap some air particles in a container whose size can vary and can be easily measured. We will measure the size of the container for various temperatures of the gas and try to use this information to determine a temperature at which the particles exert no pressure on the container. What does this suggest about the motion of the air particles at this temperature?

Scientists had suspected the existence of such a temperature for many years before Lord Kelvin first evaluated the actual temperature and proposed its use as the basis of a new temperature scale in 1848. He found this temperature to be about –273°C and he called it "absolute zero". Using this temperature as a zero point, he devised the "absolute" or "Kelvin" temperature scale, using degrees which are the same size as those on the Celsius scale. In this investigation we will attempt to find a value for this temperature and familiarize ourselves with the Kelvin temperature scale.

7.11 Investigation: Temperature / Volume of Gas

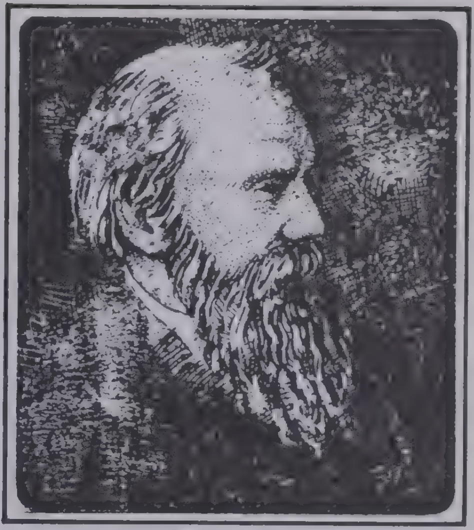
PROBLEM: WHAT EFFECT DOES TEMPERATURE HAVE ON THE VOLUME OF SPACE OCCUPIED BY A GAS?

MATERIALS:

small-bore glass tubing 30 cm long
wooden ruler marked in ml
thermometer calibrated in °C
supply of mercury

PROCEDURE:

Seal one end of the glass tubing by rotating the tip slowly in the hottest part of the flame from a burner. (Ask your teacher for help if you have any difficulty.) To ensure that the end is completely sealed, allow it to cool, and then blow through the open end with the sealed end under water. Be certain that no bubbles come from the sealed end of the tube. Now, holding the tube by the sealed end, gently heat the entire length of the tube for a few seconds before inverting the open end into a shallow dish of mercury. As the tube cools, a small piston of mercury will be pushed up into the inverted tube. After the mercury piston has reached 1 or 2 cm in length, quickly invert the tube (so that the open end is now up) and allow it to cool completely. As it cools, the small mercury piston should move down inside the tube, trapping a small quantity of air below it. Using two elastic bands, fasten this tube together with a thermometer to the wooden ruler in such a way that the sealed end of the tube is at the zero mark on the ruler, and the length of the air column below the mercury piston may be easily read in millimetres. The temperature should also be clearly visible. Place this entire assembly in a bath of boiling water and, once the mercury piston has stopped moving, measure both the temperature and the length of the air column. Repeat this



LORD KELVIN

The relationship between the volume of a gas and its temperature was first investigated in 1787 by Jacques Charles, a French chemist, and has since become known as Charles' law.

Many strange things happen at or near the temperature of absolute zero. Liquid helium, for instance, exhibits a property known as superfluidity at temperatures below about 2K. When placed in an open container, liquid helium flows up the sides of the container and out over the top edge. As you can imagine, measuring temperatures this low is extremely difficult.

same procedure by exposing the assembly to the following conditions:
1. lukewarm water bath (about 60°C)
2. room temperature water bath (about 25°C)
3. cold water bath (about 10°C)
4. ice water bath (about 0°C)
5. the freezer compartment of the lab refrigerator (about –15°C)

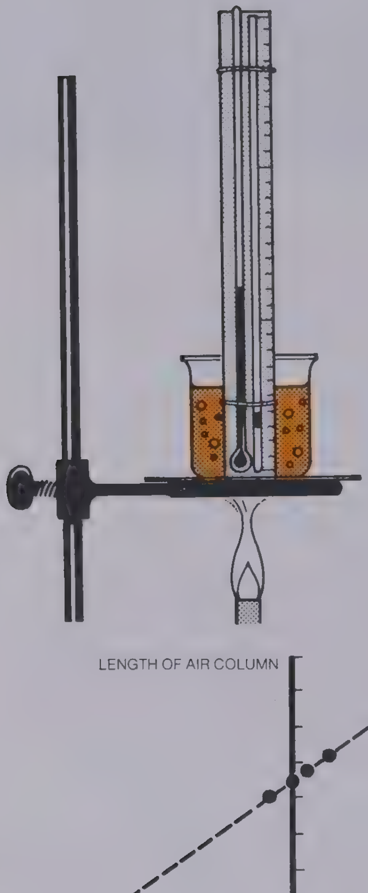
Record all of the data in a chart and draw a graph of the length of the air column versus temperature. Use a temperature axis which extends from 100°C to –300°C.

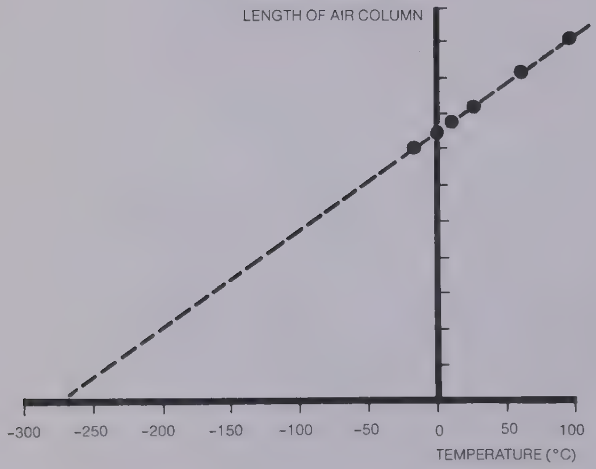
QUESTIONS:

1. Describe the shape of the graph of length of air column versus temperature. What could the length of the air column be used to indicate?
2. Could we use this graph to predict the length of the air column if we were to cool the tube down to a temperature much lower than was possible in our lab? How could we do this?
3. This process of extending the limits of our experimental data is known as "extrapolating". Extrapolate your graph to determine the length of the air column at –50°C, at –100°C and at –200°C.
4. As the temperature of a gas decreases, the volume of space occupied by the gas also decreases. Explain why this is so. Theoretically, what is the shortest possible length of the air column? Use your graph to estimate the temperature at which this occurs.
5. At this temperature, what would all of the air particles be doing? Therefore, would it be possible to lower the temperature even further beyond this point? Why not?
6. This temperature represents Lord Kelvin's "absolute zero". Using it as 0, label the temperature axis of your graph in kelvins (K) as well as in degrees Celsius. Determine the boiling point and freezing point of pure water, both in kelvins. How could any temperature on the Celsius scale be converted to its value on the Kelvin temperature scale?

7.12 Motion of Liquid Particles: Milk

As we have already agreed, the reason we cannot actually "see" the particles of a substance moving is because of their extremely small size. Suppose, however, particles which are large enough to be seen under a microscope are mixed in with some water. If the water particles are moving, what must be continually happening to the larger, visible, particles? Homogenized milk does contain a large number of very tiny





butterfat particles, which are just large enough to be visible under a microscope. Our next investigation will employ these butterfat particles to try and tell us something about the invisible water particles which make up much of the remainder of the milk.

7.13 Investigation: Liquid Particle Motion

PROBLEM: WHAT CAN WE LEARN ABOUT LIQUID PARTICLE MOTION IN MILK UNDER A MICROSCOPE?

MATERIALS:

microscope
microscope slides
homogenized milk
eye dropper

PROCEDURE:

Dilute a small amount of milk by adding an equal amount of water to it. Then place one drop of this mixture on a clean microscope slide and observe under a microscope. Use the highest power possible. Warm the microscope slide on a hotplate and observe again.

QUESTIONS:

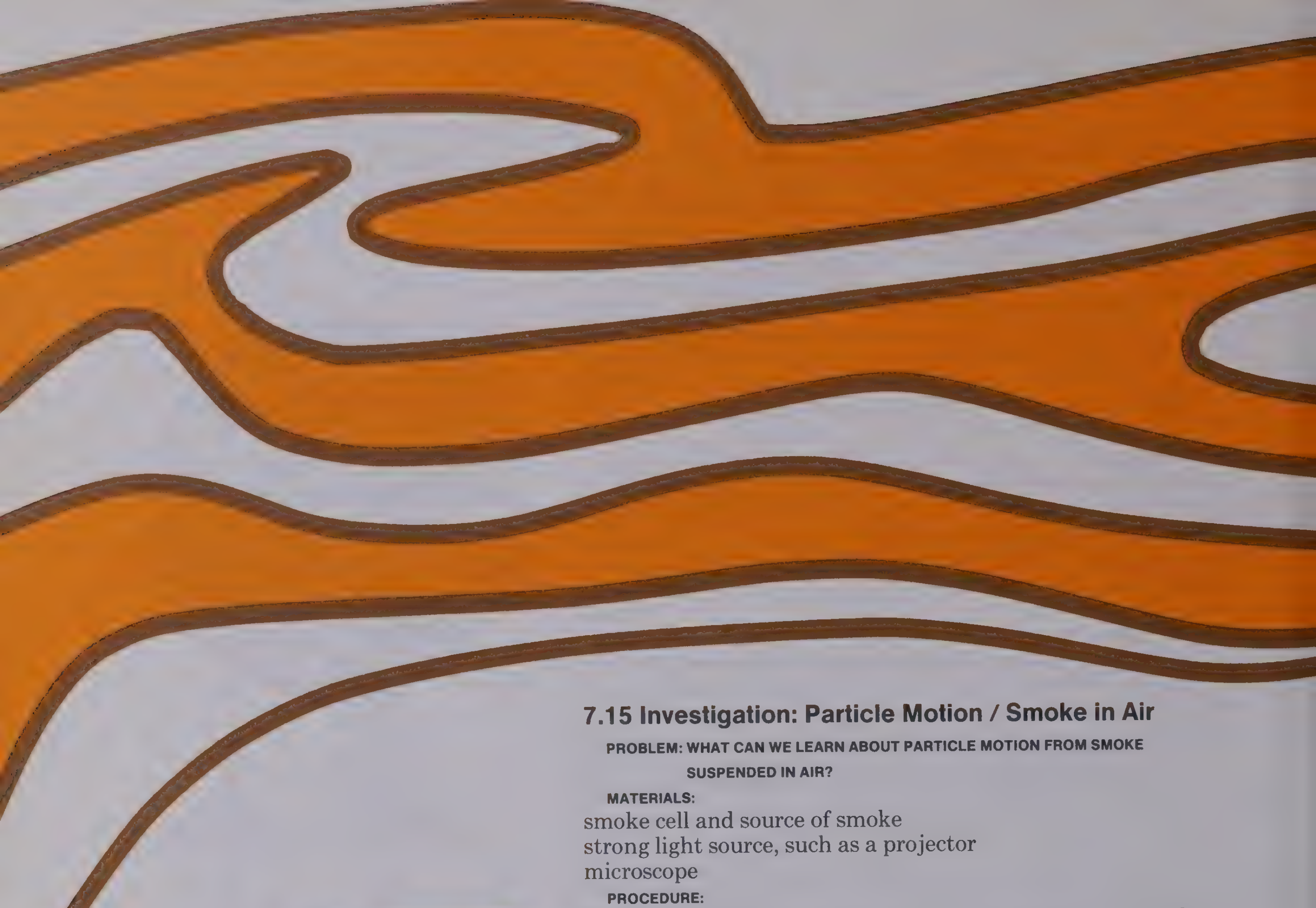
1. Why are the tiny butterfat particles moving? Are they hitting each other or is something else happening? Is there any difference in the observed motion of the hot and cold milk? Explain.
2. How does the size of the butterfat particles compare with the size of the water particles? Can you relate what you found in 7.3 about collisions between marbles of different sizes to the collisions between butterfat and water particles?
3. Why did we dilute the milk with water?

7.14 Motion of Smoke Particles: Brownian Motion

It is possible to conclude that the tiny, invisible liquid particles in milk are moving by observing the motion of milk butterfat particles with which they collide. The same type of effect can be observed in gases. Even though the particles making up air are too small to be visible, when larger, more visible particles, like those in smoke, are mixed with the air, any random motion of these smoke particles could easily be attributed to collisions with moving air particles.

This effect was noticed in 1827, by a Scottish botanist, Robert Brown, and since that time it has become known as Brownian motion. This next investigation makes use of a rather simple piece of scientific apparatus which, if not found in your school lab, can be easily made to demonstrate the Brownian motion of smoke particles.

At room temperature the average speed of the particles making up air is about 150 m/s. The particles collide and change direction about eight billion times each second.



7.15 Investigation: Particle Motion / Smoke in Air

PROBLEM: WHAT CAN WE LEARN ABOUT PARTICLE MOTION FROM SMOKE SUSPENDED IN AIR?

MATERIALS:

smoke cell and source of smoke
strong light source, such as a projector
microscope

PROCEDURE:

Place the smoke cell on the stage of a microscope, so that the low-power objective lens is situated above the top window in the smoke chamber. Set up a bright light source to shine into the smoke chamber through its side window. Do not use the microscope's own light source. Using a match which has just been extinguished, draw a small amount of smoke into the chamber and observe the smoke particles closely. Try to concentrate on one individual particle, and describe its motion.

QUESTIONS:

1. Did the smoke particles all tend to move in the same direction according to some set pattern?
2. To what could we attribute their random motion?
3. If this experiment could have been repeated at two different temperatures, one very hot and the other very cold, what differences would we have noticed in the motion of the smoke particles?

7.16 Evaporation and the Motion of Particles

In Chapter Six we studied a process by which a substance changed from a liquid to a gas – boiling. You may recall that a great deal of heat was required, first to raise the temperature of the liquid to its boiling point, and then to cause its particles to change from the liquid state to the gaseous state. What must the particles of a liquid do, as their temperature reaches the boiling point, which allows them to become gaseous?

Is there any other process by which a liquid can become a gas? Of course – evaporation! What must the particles of a liquid be able to do in order to evaporate into the gaseous state? Even if the temperature of a liquid is below the boiling point, are all of its particles travelling too slowly to escape into the gaseous state? Think of the investigation you did with the marbles in the cake tin. What would happen to a particle if it were hit on one side by two other particles and on the other side by none? What might happen to this particle if it were near the surface of a liquid?

In order to evaporate, a liquid particle must simply be moving fast enough to break away from the other liquid particles surrounding it, push through the surface of the liquid and become a gaseous particle. What factors might affect the number of particles in a liquid which are capable of doing this? The investigation which we will do next should reveal some of these factors to you.

7.17 Investigation: Particle Motion and Evaporation

PROBLEM: WHAT CAN WE LEARN ABOUT PARTICLE MOTION FROM THE EVAPORATION OF A LIQUID?

MATERIALS:

4-250 ml beakers
100 ml graduated cylinder
electric fan
alcohol

PROCEDURE:

Carefully and accurately measure out 100 ml of water into each of three beakers. Label beaker #1 "cold" and place it in the lower compartment of the lab refrigerator. Label beaker #2 "air movement" and place it on a table just in front of the fan. Label beaker #3 "control" and place it on another table,where it will be undisturbed. In the fourth beaker, measure out 100 ml of alcohol, label it "alcohol" and place it under the same conditions as the control beaker. Finally, fill the graduated cylinder with 100 ml of water and place it in the same conditions as the control beaker.

Leave all five samples as they are for one day, and then the next day, carefully measure the amount of liquid which remains in each. Record all of the data in a table which indicates the conditions under which each sample evaporated, the volumes before and after evaporation, and the percentage of the liquid which evaporated.

QUESTIONS:

1. What was the purpose of labelling one of the beakers "control" and leaving it under normal conditions?
2. Identify which conditions lead to a greater amount of evaporation than the control beaker, and which lead to less evaporation.
3. For each of the other four samples, use the moving particle theory to explain why there was more, or less, evaporation than the control.
4. Use the results of this experiment to determine under what conditions clothes will dry fastest when hung on the clothesline.

7.18 Summary

1. Two theories of heat have gained popularity. The caloric fluid theory assumes heat is a substance which flows into hot objects and occupies the spaces around the particles. The particle motion theory assumes that heat is nothing more than motion of the particles in a substance. In a hot object, the particles, on the average, are moving faster than in a cold object.

2. Collisions between moving particles in a substance may be similar to collisions between moving marbles on a track.

3. Particle motion can cause a liquid such as water to move up a wick and carry other particles, such as those in ink, with it.

4. The process of dissolving can be thought of as evidence for the particle motion theory, as rapidly moving liquid particles collide with solids, thereby breaking off particles of the solid.

5. Gases spread out from regions of high concentration as a result of collisions with other gas particles, and with particles of air, all of which are moving. This process, called diffusion, occurs faster at high temperatures and for gases whose particles are smaller.

6. Gases exert pressure on the walls of their containers as a result of collisions between the rapidly moving gas particles. At high temperatures, the faster moving particles produce a greater pressure.

7. As the temperature of a gas decreases, its particles move slower and hence occupy a smaller volume. Theoretically, at some very low temperature, the particles stop moving, so that the gas occupies no volume and exerts no pressure. This temperature is called absolute zero, and was estimated by Lord Kelvin to be approximately –273°C.

8. The Kelvin, or absolute, temperature scale begins at absolute zero, and has degrees the same size as the Celsius scale. The boiling point and freezing point of water are 273 K and 373 K respectively.

9. Evidence for the motion of liquid particles may be obtained by observing the erratic motion of butterfat particles in milk, as they are buffeted by collisions with the smaller, faster moving particles comprising the remainder of the milk.

10. Similarly, smoke particles suspended in the air move erratically as they are bombarded by the faster moving air particles. Both of these are examples of Brownian motion.

Evaporation of a liquid requires heat and an evaporating liquid absorbs this heat from its surroundings, thereby lowering the temperature of the surroundings. Evaporation of perspiration is nature's way of cooling the body when it becomes overheated. Dip a thermometer into water and then watch the temperature as the water evaporates from the bulb.

Different liquids absorb different amounts of heat when they evaporate. Those which absorb a great deal of heat, such as freon, are called refrigerants, and are used in refrigerators, air conditioners and freezing systems.

11. Evaporation is accomplished by liquid particles acquiring enough motion, as a result of collisions with other liquid particles, to break the strong forces exerted on them by other particles, penetrate the surface of the liquid, and enter the gaseous state. The factors affecting the rate of evaporation are surface area of liquid, humidity of air over surface, type of liquid and the temperature of the liquid.

7.19 Further Investigations

A piece of equipment consisting of wet- and dry-bulb thermometers is sold commercially for determining relative humidity, and is known as a hygrometer.

1. The diffusion rate of a gas may also be studied by making use of the fact that carbon dioxide does not support combustion, and as a result, a flame exposed to carbon dioxide will be extinguished. Make a strip of stiff cardboard about 40 cm long and 4 cm wide. Using a nail, make a small hole every 8 cm along the cardboard strip. Push a birthday candle into each of these holes, making sure they fit tightly. When the strip is held vertically, the candles should stick out sideways from the strip. Drop a few pieces of dry ice into a large graduated cylinder, light all of the candles and lower the cardboard strip and candles into the cylinder. As the carbon dioxide from the dry ice diffuses upward, what happens to each candle? Record the length of time for the carbon dioxide to travel 8 cm, 16 cm, 24 cm and 32 cm. The diffusion rate may be calculated by dividing the distance travelled by the time taken. What is the diffusion rate of carbon dioxide in this experiment?
2. The paper chromatograph of chlorophyll provides an interesting study. To obtain some chlorophyll, grind a few leaves from a green plant, using a mortar and pestle, and add a few millilitres of alcohol. Continue to grind and mix until the alcohol is dark green. Filter this mixture and use the filtrate to prepare a paper chromatograph of chlorophyll. Can you identify various different particles in the chlorophyll?
3. The effect of evaporation on temperature can be measured using two thermometers and a beaker of water. Make a small wick out of cotton and wrap the wick around the bulb of one thermometer so that 3 or 4 cm of cotton are hanging loosely below the bulb. Clamp the thermometer so that the bottom of the wick just dips into a beaker of room temperature water. Clamp the other thermometer beside the wet bulb but leave its bulb dry. Leave them overnight and then compare the temperatures of the wet- and dry-bulb thermometers. Which is lower? Why? The difference in the two temperatures provides a means for measuring the relative humidity – the degree to which the air surrounding the thermometers is saturated with water vapor. By consulting the chart determine the relative humidity in your lab.

You may want to take readings each day for a week and compare your results with the weather forecasts.

BULB TEMPERATURE (°C)

DRY

WET

	16	17	18	19	20	21	22	23	24	25	26	27	
10	44	40	36	33	29	25	22	18	14	10	6	4	10
11	54	50	46	41	37	33	28	24	20	15	11	7	11
12	63	58	53	49	44	39	35	30	25	21	16	11	12
13	68	63	58	53	49	44	39	34	30	25	20	15	13
14	78	73	68	62	57	52	46	41	36	30	25	20	14
15	89	83	77	72	66	60	55	49	43	38	32	26	15
16	100	94	88	82	76	69	63	57	51	44	38	32	16
17		100	94	88	82	75	69	63	57	50	44	38	17
18			100	93	86	80	73	66	60	53	46	40	18
19				100	94	87	81	74	68	61	54	47	19
20					100	93	87	80	74	67	61	54	20
21						100	94	87	81	74	68	61	21
22							100	93	87	81	75	68	22
23								100	93	86	79	72	23
24									100	93	86	79	24
25										100	93	87	25
26											100	95	26
27												100	27
	16	17	18	19	20	21	22	23	24	25	26	27	

DRY

WET

One of the reasons home humidifiers are used in winter is that humid air has a greater heat capacity than dry air. And health authorities believe relative humidities between 40% and 60% are most healthful.

4. A more dramatic example of the cooling effect of evaporation may be observed using a liquid called ether. Create a small puddle of water on a smooth glass surface and place a watch glass in the puddle. Pour a few millilitres of ether into the watch glass and fan the ether with your hand. What happens to the ether? Try to pick up the watch glass. What has happened to the puddle of water? Can you explain why this has happened?
5. The cooling unit in refrigerators and air conditioners uses the principle of an evaporating liquid to extract heat from the surroundings. Consult reference books in the library to see if you can understand how such a cooling unit works. Try to draw a sketch showing the major components of the system and make a short note on the role of each component.

7.20 Review

1. Name two prevalent theories for the nature of heat and give a short description of the major ideas involved in each.
2. Compare these two theories by explaining why dense metals have a lower heat capacity than less dense metals, from each theory's point of view.
3. Name the process used to separate ink into its component substances. Explain how this process is useful to chemists and biologists.
4. Name the process by which a gas spreads out from a region of high concentration. List several common examples of this phenomenon.
5. When automobile tire manufacturers recommend air-pressure levels, they quote two values, one for tires which are hot, and the other for tires which are cold. Why do they do this? Which would be the higher quoted value?
6. Why do manufacturers of aerosol cans warn against incinerating the cans? What would happen if a completely empty aerosol can were incinerated?
7. Convert the following Celsius and Kelvin temperatures:
   (a) 100°C to K
   (b) 0 K to °C
   (c) 37°C to K
   (d) 273 K to °C
   (e) 20°C to K
8. The mercury used in one of your investigations is potentially harmful if allowed to evaporate over long periods of time. When mercury is left out in an open container, it is often coated with a thin layer of water. Explain why this is done, and how it accomplishes its goal.
9. When rubbing alcohol is placed on the skin, it evaporates and leaves the skin cool. Can you explain this effect, in particle motion terms? How is this related to our bodily mechanism for releasing heat by perspiring?

7.21 Instructional Objectives

1. To name and describe fully the basic ideas involved in the two prevalent theories of heat, to identify which theory seems superior and to give reasons justifying its superiority.
2. To describe the results of collisions between marbles of different sizes and speeds, and to apply these descriptions to collisions between particles.

3. To identify and describe fully several examples of evidence for particle motion in both liquids and gases, and to define terminology associated with this motion (such as random, diffusion, Brownian motion).

4. To state the approximate value of absolute zero in degrees Celsius, to describe the particle motion characteristics associated with this temperature and to convert between the Celsius and Kelvin temperature scales.

5. To list the factors affecting the rate of evaporation of a liquid, and to explain fully the process of evaporation and how each of these factors affects its rate from a particle theory point of view.

7.22 Glossary

absolute zero
Francis Bacon
Brownian Motion
caloric fluid theory
Sir Humphrey Davy
diffusion
Galileo
Lord Kelvin
James Clerk Maxwell
paper chromatography
particle motion theory
Benjamin Thompson

Work

8.1 Another Look at Particle Motion
8.2 What Is Work? When Is Work Done?
8.3 How Much Work Is Done? Can We Measure It?
8.4 Investigation: Measuring Work
8.5 Can Machines Make Work Easier?
8.6 Investigation: Simple Machines
8.7 Can Heat Do Work?
8.8 Investigation: Heat / Work
8.9 Can Work Produce Heat?
8.10 Investigation: Work / Heat
8.11 Can Electricity Do Work?
8.12 Investigation: Electricity / Work
8.13 Can Light Do Work?
8.14 Investigation: Light / Work
8.15 Summary
8.16 Further Investigations
8.17 Review
8.18 Instructional Objectives
8.19 Glossary

8.1 Another Look at Particle Motion

Consider a piece of metal, such as a bolt or a nail. If we were somehow able to travel into the interior of the nail, what would we see? Since we now have a great deal of faith in the particle theory of matter, we would certainly expect to see a large number of particles, all packed tightly together. But in the previous chapter, we learned what we could expect these particles to be doing – moving back and forth rapidly and colliding with each other. The hotter the metal, the more vigorous the motion. Remember, we also said that this motion is continuous.

To understand the motion of these particles more clearly, reconsider the moving marbles we used in the kinetic-model investigation in Chapter Seven. How were these marbles put into motion? They rolled down an inclined track, picking up speed as they approached the bottom. But how did they get to the top of the track so they were able to roll down? They had to be lifted from the table top a certain distance and placed at the top of the track. It seems that the motion of the marbles was caused by lifting them and then allowing them to roll down the track.

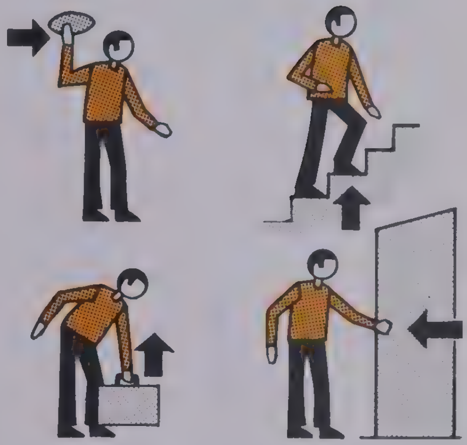
The lifting of the marble is accomplished by pulling or pushing it from the table top to the top of the track. In science, pushes and pulls are called forces. To throw a ball, lift a suitcase, open a door or even walk or climb stairs requires a force. We will learn how to measure forces later. When an upward force is exerted on the marble, causing it to move from the table to the top of the track, we say that work has been done on the marble.

8.2 What Is Work? When Is Work Done?

In science, the word "work" has quite an exact meaning, which may be somewhat different from its everyday meaning. However, most people will agree that the following are examples of work being done:

1. shovelling dirt out of a hole
2. hammering a nail into a piece of wood
3. pushing a car out of a ditch
4. climbing a ladder with a load of bricks

Can you see what all of these examples of work have in common? In each case, *a force is being exerted on an object, causing the object to move a distance in the direction the force is moving.* In each example, try to identify which object is exerting the force and which object is moving as a result of the force being applied to it.



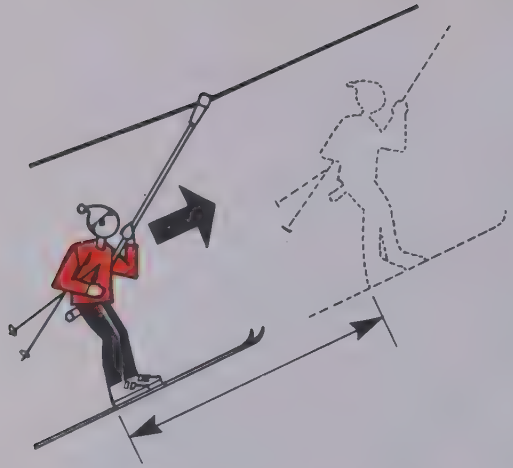
Sir Isaac Newton (1642 – 1727) was an English mathematician and philosopher. In addition to his formulation of the three basic laws of motion, he is famous for his discoveries in the fields of mathematics, gravitation, calculus, optics and thermodynamics.

"Nature and Nature's laws lay hid in night. God said 'Let Newton be'; and all was light."

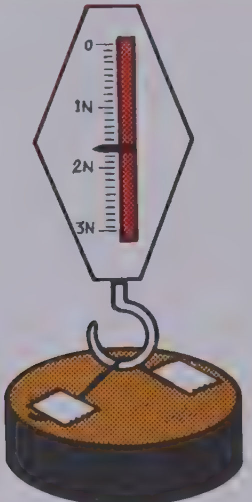
Alexander Pope
"Epitaph Intended for Sir Isaac Newton."

"Newton was the greatest genius that ever existed, and the most fortunate, for we cannot find more than once a system of the world to establish."

Lagrange



A spring balance indicates force by measuring the amount of stretch of its spring. The more force pulling on the spring, the more it stretches. What does it mean when a set of scales is labelled "no springs"?



Nowadays, machines are used to do most of our work for us:

1. a ski tow's gas engine pulls skiers up a hill
2. a bulldozer pushes dirt into a pile
3. a steamshovel digs earth from an excavation.
4. an electric motor lifts an elevator full of people

Even in these examples of machines doing work, it is quite clear that, in each case, a force applied to an object is causing the object to move a distance. In physics, we say that *work is done whenever a force is applied to an object, causing the object to move in the direction the force is moving.* The more force that is applied, the more work that is done. The further the object moves, the more work that is done.

Forces are measured in units called newtons (N), named after Sir Isaac Newton, the great seventeenth-century British physicist who first explained the nature of forces and their effect on an object's motion.

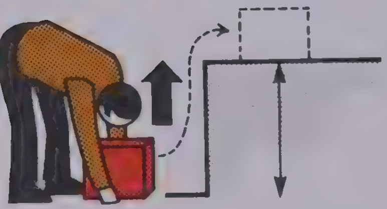
In the lab, forces are measured using a spring balance calibrated in newtons. For example, to lift a hockey puck requires a force of approximately two newtons (2 N). Our next investigation will involve measuring some small forces in the lab.

8.3 How Much Work Is Done? Can We Measure It?

Work is done whenever a force is exerted on an object, thereby moving it a distance. What factors might affect the amount of work done on an object? How would the work required to lift two books from the floor to a table compare with lifting only one book the same distance? Since it would take twice as much force to lift the two books, a good guess would be that twice as much work would be done. On the other hand, how much work would it take to lift one book from the floor to a shelf which is twice as high as the table? Once again, it would seem that, even though the force required to lift the book is the same, since the distance is doubled, twice as much work must be done. In fact, since the amount of work done on the book seems to depend only on the force needed to lift it and the distance it is lifted, we can devise the following formula to measure the amount of work done:

$W = F \times d$ where W is the work done on the object
F is the force applied to the object (measured in N)
d is the distance moved by the object (measured in m)

When F (measured in N) and d (measured in m) are multiplied together, the resulting value for work, W, would be



expressed in units called newton metres (N·m). For simplicity, we call this unit of work the joule (J). When 1 N of force causes an object to move a distance of 1 m, we say that the work done is 1 J.

When 5.0 N of force is used to lift a carton a distance of 2.4 m, the amount of work done on the carton is 12 J.

This similarity in units suggests that there may be some connection between heat and work. We will investigate this relationship more closely.

Using the formula previously suggested, we can now calculate the work done in many situations when forces cause objects to move. For example, if a force of 75 N is required to lift a package a distance of 2 m, the work done on the package is 150 J. In the following investigation we will get some practice in calculating the amount of work done.

8.4 Investigation: Measuring Work

PROBLEM: CAN WE MEASURE WORK AMOUNTS?

MATERIALS:

spring balance, calibrated in newtons
string
several blocks of wood with hooks on one end,
and eyes on the other
metre stick

PROCEDURE:

Place a block of wood on the floor and then lift it from the floor to your table top using string looped over the hook and attached to the spring balance. Lift very slowly and at a steady speed, and read the amount of force exerted on the block during the lift. Measure the distance from the floor to the table top, and record both values in a table, as below:

SITUATION	FORCE APPLIED F (N)	DISTANCE MOVED d (m)	WORK DONE W (J)
lifting one block from floor to table			
lifting two blocks from floor to table			

Whenever forces are exerted on objects, causing them to move, frictional forces occur and must be overcome. These are forces which are created when two moving surfaces rub together, and they have the effect of resisting motion. Can you use the particle theory to explain why frictional forces exist? What effect does a lubricant have on the amount of friction force between two moving surfaces? Frictional forces may also be measured in newtons.

For example, if a 30 N force is exerted to push an object which encounters a frictional force of 10 N, the force doing useful work on the object is 20 N.

Work done to overcome friction is not useful work

Repeat the same procedure using two and three blocks hooked together and lifting them from the floor to the table. Then repeat, only this time lift them from the floor to your chair.

Next, place one of the blocks face down on the table, and pull it across the length of the table with the string and spring balance. Measure the force applied and the distance moved, and record these values in your table. Repeat the same steps, only this time use two and three blocks piled one on top of another, and pull them across the width of the table. You might also try the same experiment with the blocks lying on their sides rather than on their faces.

For each situation investigated, calculate the amount of work done on the block(s) and record these values in your table.

In his law of inertia, Newton stated that once an object is moving, it continues to move of its own accord, in a straight line and at a steady speed, unless acted upon by some external force. What effect would frictional forces have on this motion?

QUESTIONS:

1. As you exert the forces slowly, and at a constant speed, what do you notice about their value during the time when the objects are being lifted or pulled?
2. In the second part of this investigation, why is it necessary to exert a force on the block just to slide it across the table? If you stop exerting the force, why will the block stop moving? Is the work done, in this case, useful work?
3. What factors seem to affect the amount of force needed to slide an object across a table? How could this force be reduced?
4. If friction between the block and the table top could be eliminated, how much force would it then take to keep the block moving? Would any work be required to keep the block moving across the table? How about getting it moving to start with? Would any force, and hence work, be needed to start it moving?
5. Suppose your task is to move three blocks from one end of the lab bench to the other, using the minimum amount of work possible. There are various ways of doing this: making three separate trips pulling one block at a time, piling the three blocks on top of one another or joining them end to end in one trip. Try to determine, experimentally, which technique would require the least amount of work to get the three blocks from one end of the bench to the other.

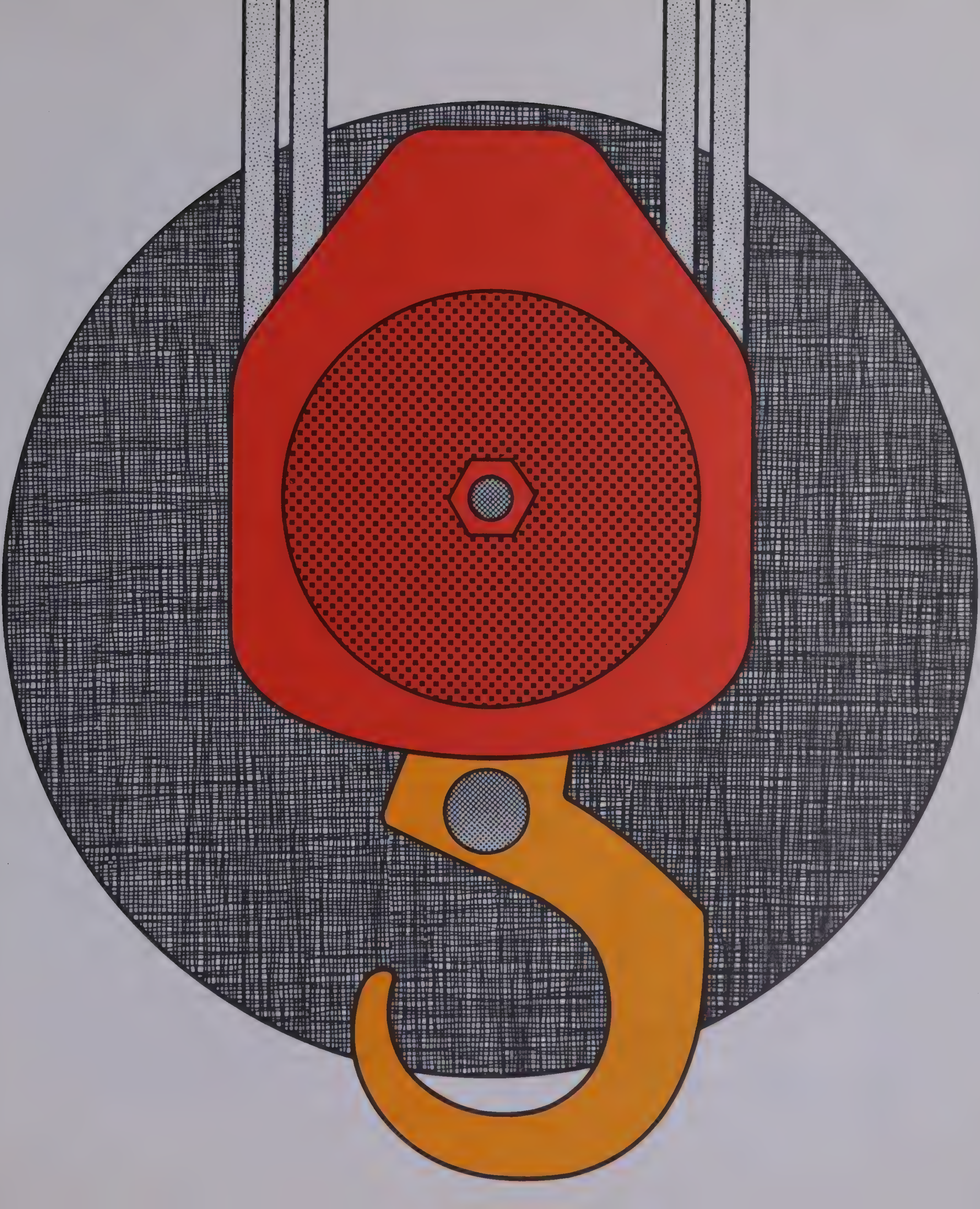
8.5 Can Machines Make Work Easier?

The word "machine" suggests to us a bulldozer, an air compressor or perhaps a snowmobile. They all seem quite different from one another, and extremely complicated. A closer look will convince you that they are similar. They are all combinations of a few simple machines, each known and used by man for thousands of years.

The simplest of machines are the inclined plane, the lever and the pulley. There are a few others but even they are mainly variations of these three. It is the aim of the next investigation to acquaint you with these machines, and to show how they can make work easier to do.

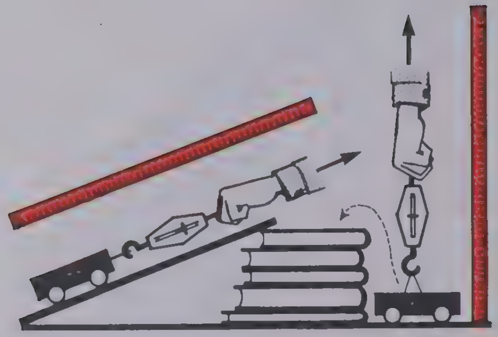
A wedge (such as the head of an axe) is simply an inclined plane. It is the plane which moves, rather than the object upon which the work is being done.

Another simple machine which is related to the inclined plane is the screw thread. Draw a sketch of an inclined plane (as a triangle) on a piece of paper, cut it out and wrap it around a pencil. What does it look like? A screw thread is simply an inclined plane wrapped around a cylinder. As you go up the plane, you also go around the cylinder.



8.6 Investigation: Simple Machines

PROBLEM: HOW DO SIMPLE MACHINES MAKE WORK EASIER?



PART A: THE INCLINED PLANE

MATERIALS:

pile of books
dynamics cart
spring balance, calibrated
 in newtons
metre stick

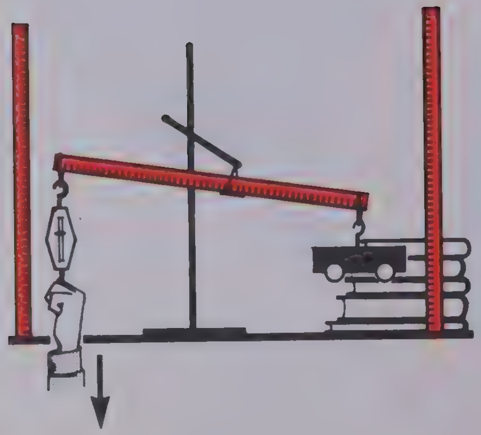
PROCEDURE:

Make a pile of textbooks about 20 cm high. Attach a spring balance to the cart with a loop of string and lift it straight up to sit on the pile of books. Measure and record the lift distance (in m) and the lifting force (in N) and calculate the work done on the cart (in J). This represents the amount of work necessary to lift the cart without using a machine and will form the basis for comparison for the rest of this investigation.

Now, using the board, set up a ramp and slowly pull the cart up the ramp from the table top to the top of the pile of books. Do this by applying a force to the cart parallel to the ramp and measure this force using a spring balance. Record the length of the ramp and the average force applied to the cart, and calculate the work done on the cart.

QUESTIONS:

1. Which required more force, lifting the cart straight up, or pulling it up the ramp?
2. Calculate the "mechanical advantage" of the ramp by dividing the lifting force by the force required to pull the cart up the ramp. The mechanical advantage of a machine tells us how much easier the work is when the machine is used.
3. Which requires more work, lifting the object straight up or using the ramp? Why?
4. Why do we say the ramp makes the work easier?
5. Make a ramp with a different mechanical advantage. Try using longer or shorter ramps. What did you discover?



PART B: THE FIRST-CLASS LEVER

MATERIALS:

retort stand and clamp
dynamics cart
spring balance
string
books
metre sticks

PROCEDURE:

Make a lever like the one shown in the diagram. The cart will be lifted when a downward force is applied to the other end of the metre stick. The metre stick is supported by the retort stand and the point of support is called the fulcrum. Adjust the metre stick so that the fulcrum is 20 cm from the string supporting the cart. Now lift the cart up to the level of the books by pulling down on the other end of the metre stick with a spring balance. Measure and record the force applied to the metre stick, and the distance this force moves in lifting the cart, and then calculate the work done on the lever.

QUESTIONS:

1. Which requires more work, lifting the cart straight up, or using the lever?
2. Which requires more force?
3. What is the mechanical advantage of your lever (force to lift directly divided by force applied to lever)?
4. Make a lever with a different mechanical advantage (try moving the fulcrum). What did you discover?

PART C: THE SECOND-CLASS LEVER

MATERIALS:

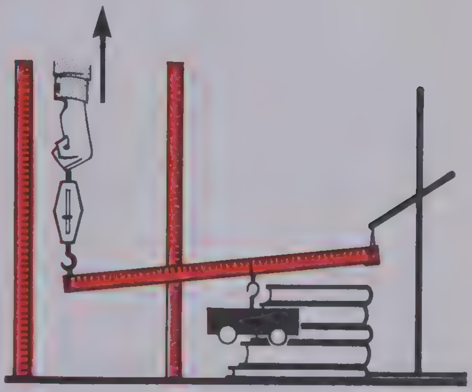
same as Part B

PROCEDURE:

Repeat Part B, but this time use a lever with the fulcrum at one end, the lifting force applied at the other end, and the cart suspended somewhere between. Again, measure the lifting force applied to the lever, the distance this force moves and calculate the work done on the lever to lift the cart up to the height of the pile of books.

QUESTIONS:

1. Calculate the mechanical advantage of your second-class lever.
2. How does this lever make work easier to do? Can you describe any devices which employ the principle of the second-class lever to do work?
3. Can you change the mechanical advantage of this lever? How? What effect does changing the mechanical advantage have on the force applied to the lever, and the distance this force must move in lifting the cart?



Examples of second-class levers are:
- a wheelbarrow
- a nut cracker
- a bottle opener

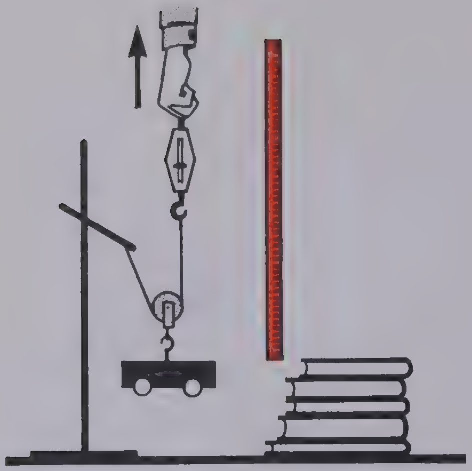
PART D: THE SINGLE, MOVING PULLEY

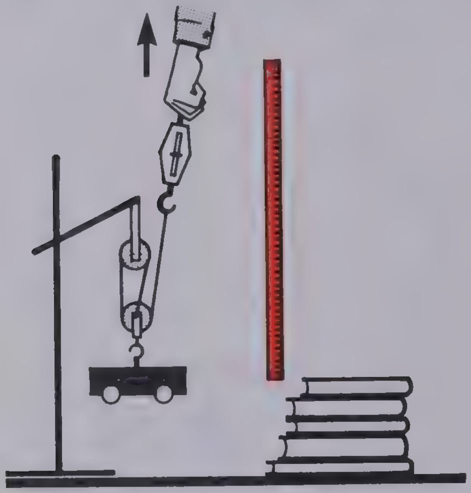
MATERIALS:

single pulley
other materials same as Part B

PROCEDURE:

Set up the pulley as shown in the diagram. Using a spring balance, lift the cart up to the height of the pile of books, and carefully record and measure the lifting force required and the distance this force moves in lifting the cart. Calculate the work done in lifting the cart.





The force exerted by a machine on an object is often called the "load", while the force exerted by a person on a machine is called the "effort". Thus:

$$\text{mechanical advantage} = \frac{\text{load}}{\text{effort}}$$

Any machine with moving parts encounters the problem of frictional forces between moving parts which come into contact. These forces, which decrease the mechanical advantage of the machine, are often minimized using bearings and lubricants. The greater the efficiency of a machine, the less frictional forces it has.

QUESTIONS:

1. Do you do more or less work by using a pulley rather than by simply lifting the cart?
2. How does the force required when using the pulley compare with the force needed to lift the cart directly?
3. What is the mechanical advantage of the pulley?

PART E: THE BLOCK AND TACKLE

MATERIALS:

several single pulleys
other materials same as Part B

PROCEDURE:

Arrange two pulleys and the retort stand as shown in the diagram. The fixed upper pulley is called the tackle and the movable lower pulley is the block. Once again, measure the force required to lift the cart, the distance this force moves and calculate the work done.

QUESTIONS:

1. Calculate the mechanical advantage of this block and tackle. The mechanical advantage can be increased by using more than one pulley on the block and the tackle. Try to devise a block and tackle with a greater mechanical advantage using more than two pulleys.
2. Does the block and tackle, or any other of these machines, make it possible to accomplish a task using less work? In fact, we have found that it may take even more work using the machine. Why is this so? What problem do we encounter when using a machine to do work?
3. We can define the "efficiency" of a machine as

$$\frac{\text{work done } \textit{by} \text{ machine}}{\text{work done } \textit{on} \text{ machine}} \times 100\%$$

Calculate the efficiency of each of the machines used in this investigation. Note that, in each case, the work done *by* the machine is just the work that would be done in lifting the cart directly to the height of the pile of books.

4. What does the mechanical advantage tell you about a machine?
5. What would a mechanical advantage of one-half mean? Explain.

8.7 Can Heat Do Work?

Work could be done on a long bar of metal in many ways. You could push it along a table, lift it up onto a shelf, throw it up into the air or hold it by both ends and stretch it. In each case, a force applied to the bar is causing it to move a measurable distance in the direction of the force, and as a result work is being done.

Of course, the last example would be the most difficult for us to do. Even though the amount of stretching (i.e., distance) would be small, the force required to stretch the rod this distance would be enormous, and hence a very large amount of work would be required. Heat is able to do this work for us quite easily.

According to our earlier investigations, the metal bar is composed of rows of particles, all moving rapidly back and forth, colliding with each other. If more heat is added to the bar, this motion should increase, causing the particles to collide with a greater force. As these particles push each other further apart, thereby doing work on each other, the length of the bar should increase.

Another example of heat doing work occurs in a simple steam engine. Heat causes water in a closed cylinder to boil, creating steam which expands and pushes a piston, thereby doing work on the piston.

This, of course, is just a prediction based on our moving particle theory. We can test the theory by testing the prediction.

8.8 Investigation: Heat / Work

PROBLEM: CAN HEAT DO WORK?

MATERIALS:

retort stand
glass microscope slide
Bunsen burner
pile of books
sewing needle
drinking straw
protractor

PROCEDURE:

We are going to heat the retort stand rod and measure how far it stretches using the needle, straw, microscope slide and protractor. Set up the equipment as shown .

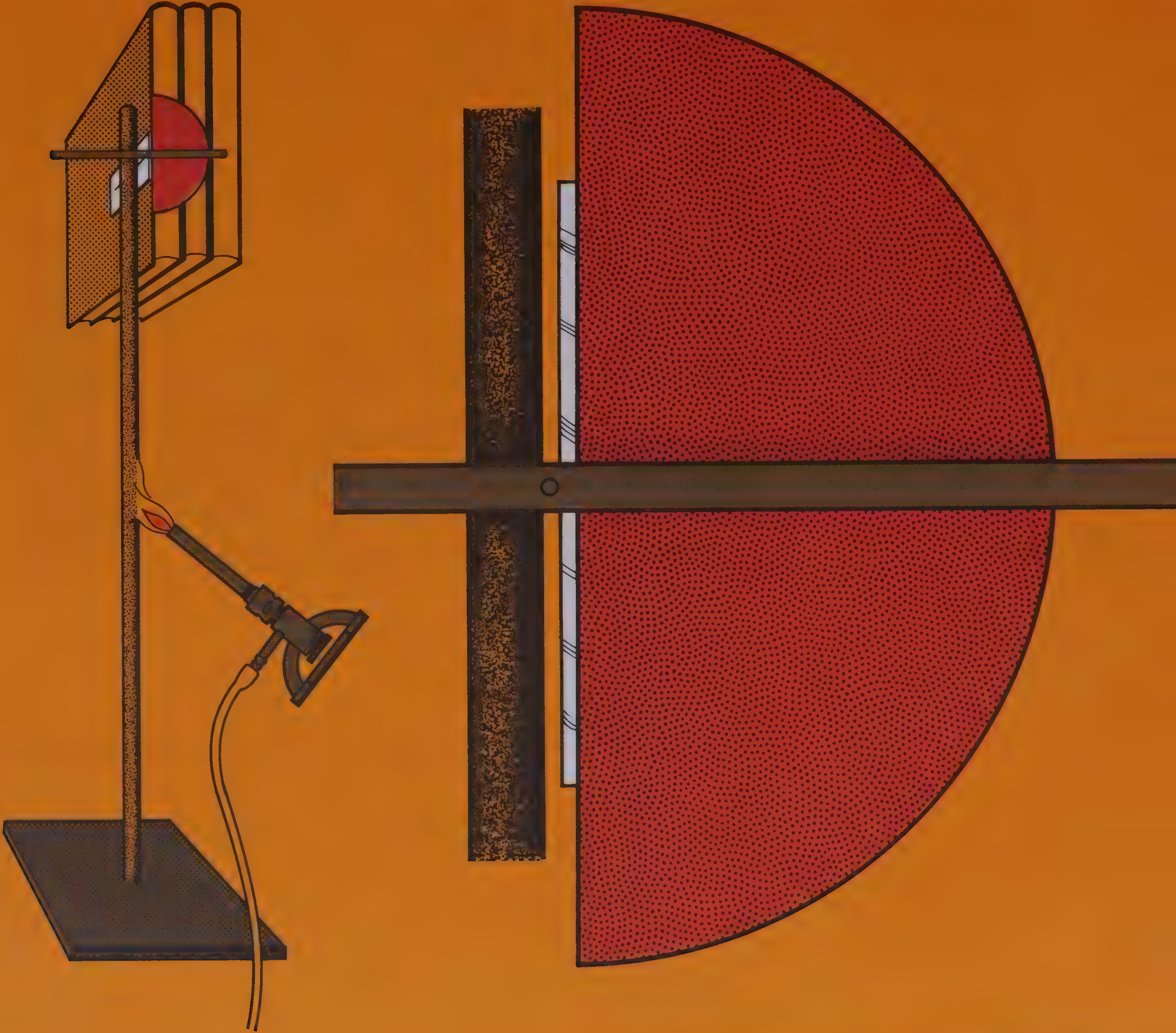
Do you realize that much of the pain of the dentist's drill results from heat generated by the bit?

The retort stand should rest on the needle, which is resting on the microscope slide. The straw should be vertical, in front of the protractor. You can test the apparatus by gently sliding the base of the retort stand back and forth. The needle should roll along the glass slide, causing the straw to rotate in front of the protractor, so that the amount of rotation can be measured in degrees.

Hammering a nail continuously will cause the nail to get hot. Long ago, the blacksmith started the daily fire on his forge by hammering a scrap of waste iron until it was hot enough to ignite some paper or kindling wood.

Heat the rod evenly up and down its entire length and observe the maximum rotation of the straw. If possible, measure the amount of rotation with the protractor. Be very careful if the retort rod is aluminum, since a burner flame is often hot enough to melt aluminum. Allow the rod to cool and observe the straw as it does so.

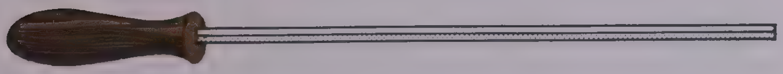
If you have time, and can be very careful, you can go one step further and calibrate the needle and straw. Slowly move the retort base forward until the straw has made one complete revolution. By placing marks on your table, determine how far forward the retort base was moved. What amount of stretching



does one complete revolution of the straw represent? How much did the retort stand stretch, in millimetres, when you heated it?

QUESTIONS:

1. By heating the retort rod, you increased its length. Do you think its width increased also? Can you think of a simple way to measure this?
2. If you were to use the proper machine, you could grab both ends of the rod and stretch it. Would its width increase this time? Would its volume change?
3. If a metal plate were heated, it would expand in all directions. If the plate had a hole drilled through its middle, would the hole increase or decrease in diameter when heated? Explain. Ask your teacher about the ball and ring apparatus.
4. Do all metals expand the same amount when heated? Suppose two different metals were fused together to form a long strip, as shown:



If the strip were heated, what would happen to its shape? Which metal expands more when heated? Can you think of any device which operates by using this principle?

If you have a thermostatically controlled furnace at home, remove the coverplate from the thermostat and observe the bimetallic strip (usually in the form of a coil). Remove the shade from a small lamp, turn it on and bring the bulb close to the thermostat. Can you see the action of the bimetallic strip?

8.9 Can Work Produce Heat?

In our previous investigation we discovered that heat could do work on a bar of metal by stretching it, a job which requires a large amount of force exerted over a rather small distance. There are many other examples of situations in which heat can be seen doing work: e.g., steam engines, heat causing the mercury in a thermometer to be lifted up to a higher level, heat causing a rubber band with a mass suspended from it to stretch.

In many instances, when a new scientific phenomenon is discovered we often wonder whether the reverse of the phenomenon would hold true. In this case, since heat can cause work to be done, we might expect some heat to be created when work is done. Many of the examples of work that we have seen involve pushing an object along a horizontal surface, or lifting an object from one level to another. Our next investigation will allow us to study some examples of work which produces heat.

8.10 Investigation: Work / Heat

PROBLEM: CAN DOING WORK PRODUCE HEAT?

MATERIALS:

paper clips
wood
sandpaper
test tube and stopper with thermometer inserted in it

PROCEDURE:

When scissors or knives are being sharpened by a rapidly moving grinding wheel, enough heat is produced to ignite small fragments of excess metal and to make them burn. We see these burning fragments as sparks.

Holding the paper clip with one half in each hand, quickly bend these halves back and forth several times. Are you doing work on the paper clip? Feel the area of the clip where most of the bending is occurring and describe your observations. Sand the wood by pushing the sandpaper back and forth vigorously several times while pressing down on the wood. Describe what you feel when you touch the area of the wood which was sanded. Try making the same observations on the sandpaper.

Finally, half fill the test tube with cold tap water, and record its initial temperature. Now insert the stopper tightly into the test tube, taking great care not to break the thermometer, and shake the test tube vigorously for several minutes. Record the final temperature and compare it with the original temperature.

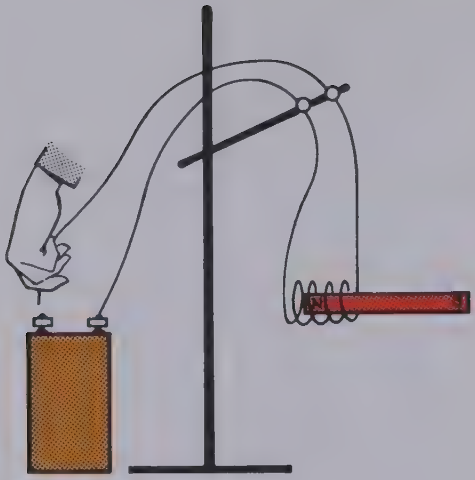
QUESTIONS:

1. In each of the three examples, try to account for the temperature change which resulted, in terms of the moving particle theory of heat.
2. Many power tools do work on wood, metal and plastics in much the same way as the sandpaper and wood in our investigation. Do the same temperature changes occur when using these power tools? What attempts are made to reduce the amount of heat produced by high-speed power tools?
3. Even the youngest children learn very early in their lives how to warm their hands in winter. Can you feel how rubbing your hands together is similar to sanding wood? What happens to the particles of your hands as you rub them together?
4. Describe several ways of starting a fire, using the results of this investigation.

8.11 Can Electricity Do Work?

We rely on electricity to make electric washers, dryers, toasters, blenders, stoves, fans and even electric knives do work.

In some cases, the electricity heats a wire, by a kind of electrical friction, to produce heat. This heat can then do useful work. In other cases, electricity and magnetism combine, in electric motors, to do work. The simplest form of this interaction can be examined in our next investigation.



If the coil is wound around a pivoted bar of iron, and this assembly is placed between the jaws of a horseshoe magnet, electricity will cause the coil to rotate. This demonstrates the principle of the motor.

Conversely, work can also produce electricity. If the battery is removed from the coil and replaced by an electrical meter (to measure the flow of electricity), any motion of the coil will cause electricity to flow through the coil and meter. This is the principle of the generator. Do you see any relation between the generator and the motor?

8.12 Investigation: Electricity / Work

PROBLEM: CAN ELECTRICITY DO WORK?

MATERIALS:

roll of thin copper wire
1½-volt dry-cell battery
2 bar magnets

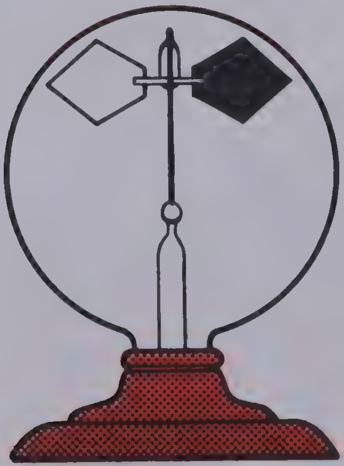
PROCEDURE:

Make a coil of copper wire consisting of about five loops, as shown. Suspend the coil from a retort stand, as shown. Connect one long lead from the coil to one terminal of the battery and support the bar magnet so that its North pole lies within the coil. Touch the second lead from the coil to the other terminal of the battery. Observe the effect this has on the hanging coil.

QUESTIONS:

1. How do you know that electricity from the battery is doing work on the coil of wire?
2. What happens if the opposite pole of the magnet is inside the coil? Make a guess, and then try it.
3. What happens if the terminals of the battery are reversed? Try to check, using both poles of the magnet as well.
4. What happens if more loops are used on the coil? Is the amount of force increased or decreased? If the force doubles, does the amount of work double? Explain.

8.13 Can Light Do Work?



We have seen that heat and electricity both have the ability to do work, because in both cases a force was exerted causing an object to move a certain distance in the direction of the force. Our next investigation will try to determine if light can do work. To do this we will employ a piece of laboratory apparatus known as Crookes' radiometer. This device is merely a small pinwheel, mounted so that it can rotate freely on a smooth pivot inside a glass bulb from which most of the air has been withdrawn. You will notice that one side of each of the four vanes of the radiometer is dark and dull while the other side is bright and shiny.

If light can cause this pinwheel to rotate, then light must be capable of doing work.

8.14 Investigation: Light / Work

PROBLEM: CAN LIGHT DO WORK?

MATERIALS:

Crookes' radiometer
light bulbs of different sizes
socket for bulbs
stopwatch
metre stick

PROCEDURE:

Place the radiometer on your table and screw the highest-power light bulb into the socket. Turn on the light and place it near the radiometer. Observe and describe carefully any motion of the radiometer. Place the light a convenient distance from the radiometer so that the rotation rate of the vanes is just as fast as you can count. Using a stopwatch, count the number of rotations of the vanes in 10 s, and record this number together with the distance of the radiometer from the light bulb, as follows:

Power of bulb (in watts)	Distance from light to radiometer (in cm)	No. of rotations of radiometer (in 10 s)

William Crookes devised the radiometer in the early nineteenth century to demonstrate that light exerts a small pressure on objects it encounters.

Repeat the same measurement, using bulbs of as many different sizes as possible, but without changing the distance to the radiometer. Plot a graph of the number of rotations of the radiometer in 10 s, versus the size of the bulb, measured in watts.

Now, return to the largest bulb and gradually move it further from the radiometer, stopping every 10 cm. At each of these points, measure the distance from the radiometer and the number of rotations in 10 s, and record all of these data in your table. Try to get at least five different readings of rotation rate and distance. Plot another graph of number of rotations in 10 s versus distance from the bulb.

QUESTIONS:

1. What evidence is there that light is causing work to be done on the radiometer?
2. Is the amount of work done on the radiometer a constant? What does it seem to depend upon?
3. Which way does the radiometer rotate – dark side trailing or bright side trailing? Since the light is shining equally both on the bright side and on the dull side of each vane, which side seems to be getting the greater push?
4. Why was most of the air removed from the glass bulb of the radiometer?

The mechanism by which the light causes the radiometer to rotate is complicated and involves the fact that some air remains inside the glass. When the light hits a dark vane the dark vane warms up slightly, and warms the air particles next to it, causing them to move faster. Light hitting the shiny vane causes very little heating, since most of it is reflected. The air particles next to the shiny vanes are moving slower than those next to the dark vanes. There is an unequal push on each vane when air particles collide with each side of it, and since the push on the dark side is greater, the radiometer rotates with the dark side trailing.

8.15 Summary

1. Work is done, in a physical sense, whenever a force acts on an object, causing the object to move in the direction of the force.

2. Forces are defined as any type of push or pull which is exerted on an object, and may be measured in units called newtons (N).

3. The amount of work done depends on the force applied and on the distance moved, and may be calculated using the formula:

   $W = F \times d$ where W = work done on object
   F = force applied (in N)
   d = distance moved (in m)

4. Work is measured in units called joules (J). One joule of work is done when a force of 1 N acts on an object, causing it to move a distance of 1 m.

5. In many cases, work must be done on an object to overcome frictional forces which tend to keep the object from moving. In these cases, we say that no "useful" work is being done.

6. Machines can be used to make work easier. This is accomplished by doing the work over a greater distance, thereby requiring less force. The basic machines used are:
   (a) the lever
   (b) the inclined plane
   (c) the pulley

7. The degree to which the machine makes the work easier to do is called the "mechanical advantage" of the machine, and may be calculated as follows:

   $$\text{M.A.} = \frac{\text{force required to do work, \textit{without} machine}}{\text{force required to do work, \textit{using} machine}}$$

8. Since all machines are affected by friction, some non-useful work is always done when using a machine. The efficiency of a machine may be calculated as follows:

   $$\text{Efficiency} = \frac{\text{work done \textit{by} machine}}{\text{work done \textit{on} machine}} \times 100\%$$

9. Investigations can be done to demonstrate that heat, electricity and light are all capable of doing work by exerting a force and causing an object to move in the direction of the force.

8.16 Further Investigations

1. Work can be done on an elastic band, causing it to stretch. Suspend an elastic band from a retort stand and measure its normal length. Hang various objects from the band, and in each case measure the amount of stretch of the elastic. Then determine the weight of each of the objects, using a spring balance calibrated in newtons. Realizing that the weight of the object is the force stretching the elastic, draw a graph of force versus amount of stretch. Describe the shape of the graph. A stretched elastic band possesses energy because of the work done on it in stretching it. This energy is called elastic potential energy.
2. A simple electromagnet may be made by wrapping wire around a cylindrical iron core (such as a large nail) and connecting the end of the wire to the terminals of a battery. Firmly connect one end, but just touch the other end to the terminal (for no more than 30 s at once). Use various numbers of windings and, for each, determine the number of paper clips the magnet can pick up. Draw a graph of number of windings versus number of paper clips picked up. Repeat, using a different material (plastic, aluminum, copper, wood) for the core. Determine the effect of number of windings and core material on the amount of force a magnet can exert. How is this related to the amount of work it can do, and hence the amount of energy it has?
3. The effect of color in absorbing and emitting heat can also be observed in the following demonstration. Take two identical cans (from vegetables, soup or juice) and remove their labels. Rub one with fine steel wool until its surface is bright and shiny. Hold the other over a Bunsen burner with a high orange flame until it is completely coated with dark, heavy soot. Fill the shiny can with boiling water and place it next to a Crookes' radiometer in a dimly lit room. Count the number of revolutions of the radiometer in one minute. Repeat, using the dark, sooty can, keeping it the same distance from the radiometer. Compare the two rotation rates and account for any differences.

A high-speed photograph of a tennis ball bouncing on the ground would show that its shape is greatly altered at the moment of impact. As its shape springs back to normal, the ball bounces back into the air.

8.17 Review

1. State clearly the two conditions which must be fulfilled before work can be done on an object, and using that criterion, determine if any useful work is done in each of the cases below:
   (a) a shovelful of dirt is lifted from the bottom of a hole to ground level
   (b) a curling stone is sliding at a steady speed across a

smooth, level sheet of ice
   - (c) a stone is placed in a slingshot, pulled back and released
   - (d) a large stone is pushed by a man, but he cannot move it
2. Calculate the amount of work done in each of the cases below:
   - (a) a force of 120 N is used to lift a shovelful of snow to a height of 2.5 m
   - (b) a force of 400 N pushes a wagon a distance of 1.2 m
   - (c) a force of 50 N pulls up on the end of a second-class lever, lifting it a distance of 50 cm (Be careful!)
   - (d) a magnet exerts a force of 4.0 N on a coil of wire, moving it a distance of 15 mm
3. Which is a better lever, one whose efficiency is 75% or 60%? Explain why. What factors contribute to the efficiency of a machine?
4. Determine the mechanical advantage of each of the following machines:
   - (a) a force of 200 N downward on one end of a seesaw causing an upward force of 500 N on a boy sitting on the other end
   - (b) a force of 600 N would normally be required to lift a bag of cement but it may be placed in a wheelbarrow and lifted by an upward force of 240 N on the handles
   - (c) a boat may be pulled up on shore by a block and tackle using a force of 200 N when a force of 1500 N would be required without the use of the block and tackle
   - (d) to lift a crate to a shelf requires a force of 400 N but to slide it up a ramp only requires a force of 160 N
5. Explain how machines can make work easier to do and give examples to illustrate your explanation.
6. Large structures such as bridges are built with expansion joints included. Explain why this precaution is taken and what would happen if it were not.
7. Explain how heat can cause work to be done in the lifting of a large, man-carrying balloon. Can you relate this idea to your study of flotation and buoyancy in Chapter Four?
8. One of the investigations in this chapter demonstrated that electricity could do work. Often when work is done to rub two substances vigorously together, electricity can be produced. Give several examples of this phenomenon.
9. Since light and heat both are capable of doing work, they must have something in common. Describe an experiment you could perform with a glass lens (such as one from a flashlight or magnifying glass) to show the relationship between light and heat.
10. Why do Arabs and others living in extremely hot climates

Efficiency of Machines

Machine	*Efficiency*
steam locomotive	8-10%
gasoline engine	30%
diesel engine	40%
jet engine	50-70%
rocket engine	90%

wear light-colored clothing? On a hot summer day, if you were walking in bare feet, would you prefer to walk on the cement sidewalk, or on the asphalt road? Explain.

8.18 Instructional Objectives

1. To state the conditions under which work is done, in a physical sense.

2. To state the unit used to measure forces, and to be able to measure simple forces using a spring balance calibrated in these units.

3. To state the formula and unit used to measure work, and to be able to calculate the amount of work done in simple instances when the force and distance are known.

4. To describe the operational mechanisms by which simple machines, such as the lever, pulley and inclined plane, make work easier to do.

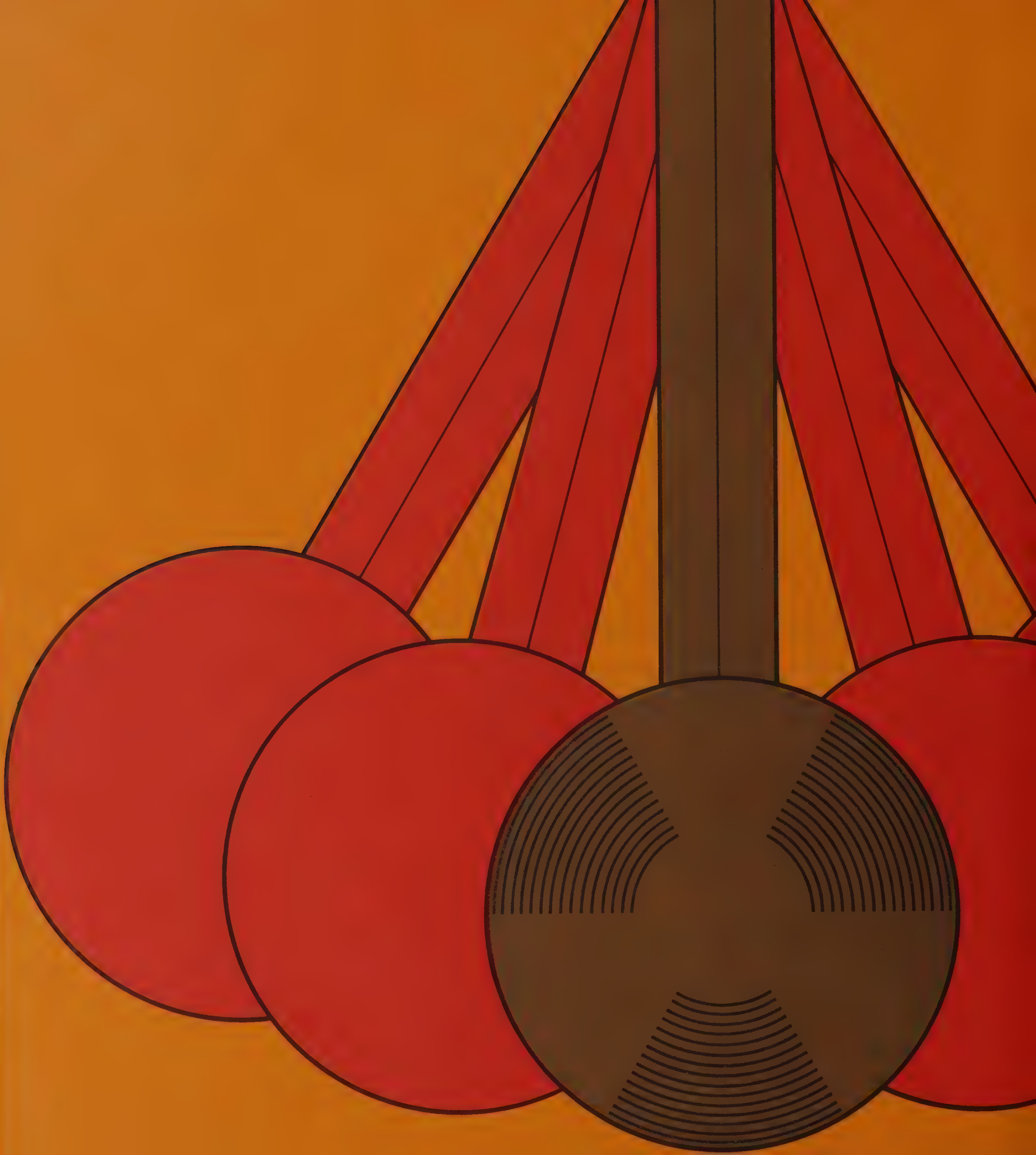
5. To calculate, by experimenting, the mechanical advantage and efficiency of a simple machine.

6. To account for the fact that machines are not 100% efficient and to describe the role of friction in machines.

7. To describe experiments which demonstrate that heat, electricity and light are all capable of doing work.

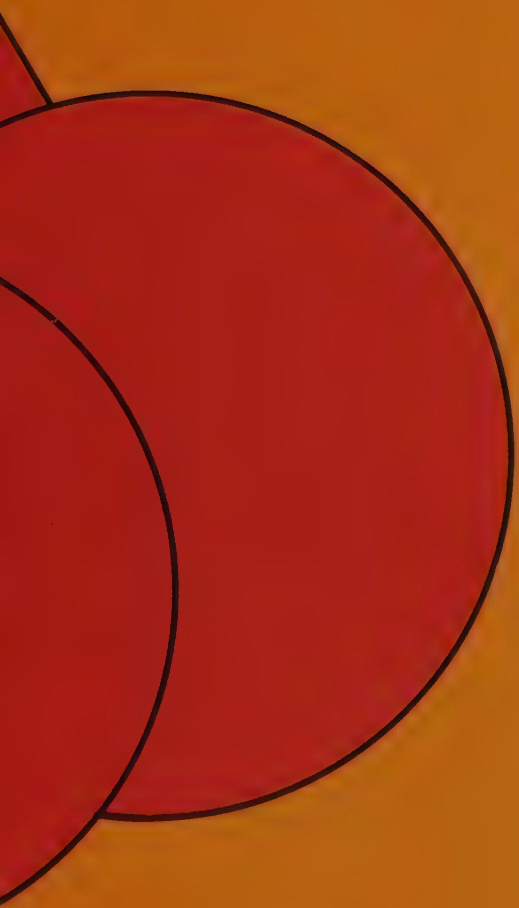
8.19 Glossary

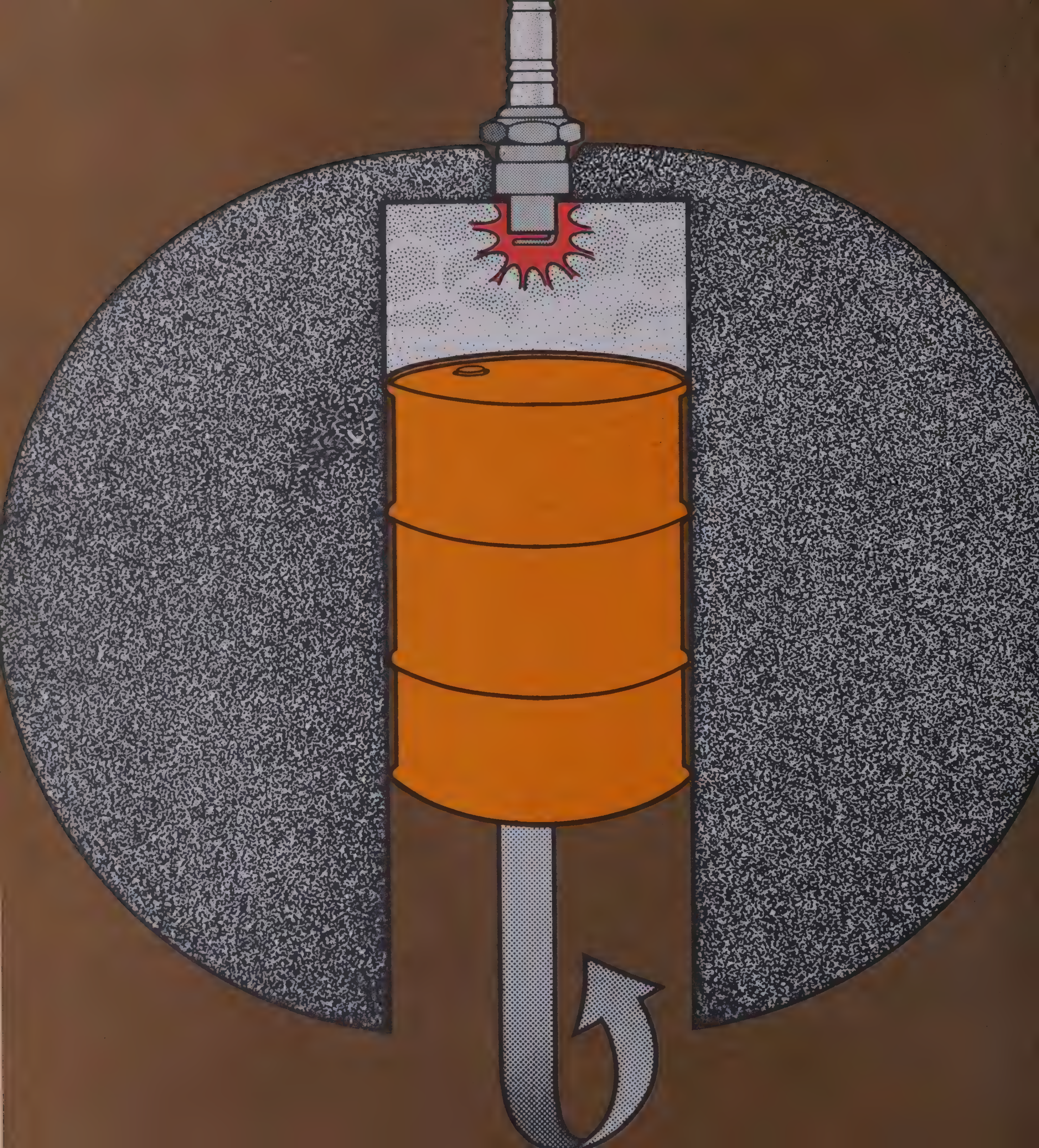
block
Crookes' radiometer
efficiency
first-class lever
force
friction
fulcrum
inclined plane
lever
magnetic force
mechanical advantage
newton
newton metre
pulley
second-class lever
tackle
work



Energy

9.1 Energy: What Is It?
9.2 Kinetic Energy: Energy of Motion
9.3 Investigation: Kinetic Energy
9.4 Gravitational Potential Energy: Energy of Position
9.5 Investigation: Gravitational Potential Energy
9.6 Conversion of Mechanical Energy: The Pendulum
9.7 Investigation: Energy Conversion
9.8 Chemical Potential Energy: Energy Stored in Matter
9.9 Investigation: Energy in Fuel
9.10 The Energy Crisis: What Can Be Done?
9.11 Summary
9.12 Further Investigations
9.13 Review
9.14 Instructional Objectives
9.15 Glossary





9.1 Energy: What Is It?

In the last few years, one of the world's greatest concerns has been the so-called "energy crisis". Governments and industries have become increasingly conscious of the amount of energy being used, and the alarming possibility that the world's supply of energy may run out. Those countries which have an abundance of energy resources have become economically and politically strong. The concepts of energy use, energy sources and management of energy resources have become watchwords of the 1970's.

In this chapter, we shall try to understand what energy is, how energy can be used, and why we must continue to find new energy sources.

Crude oil is one of the world's foremost sources of energy. Hardly a week passes without some mention of oil and petroleum developments in the media. What can oil do for us, as a result of the energy it possesses? It can be burned and as a result produce heat (in oil burners) and light (in kerosene lamps). When it is ignited and explodes in an automobile engine it can push the pistons and thereby drive the car along a road or up a hill. It can cause the car's generator to operate, thereby producing electricity for the headlights and radio. But these instances of pushing, lifting, heating and producing light and electricity are already familiar to us from our investigations of Chapter Eight. We found that heat, light and electricity were all capable of lifting or pushing objects various distances, and as a result, of doing work. It seems that crude oil, because of the energy it possesses, is capable of doing work.

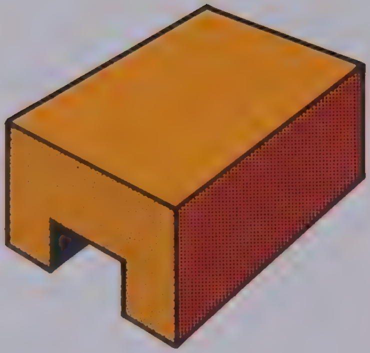
This ability to do work is an excellent definition of what we mean by energy. Anything that can do work must possess energy. In addition, we will measure the amount of energy something has by measuring the amount of work it is capable of doing. Do you remember how to measure work?

There are many kinds of energy available to us. In some cases the energy is easily visible because it is obvious that the object possessing the energy has the ability to do work. For example, a speeding automobile or a hockey puck shot by Bobby Hull both possess energy since they are capable of colliding with other objects, thereby pushing them and doing work on them. On the other hand, the energy contained in a match, a peanut butter sandwich or a piece of radioactive uranium is not as easy to visualize.

In the investigations that follow, we will identify some of the more common types of energy, show that objects possessing these types of energy can do work and then determine the factors which affect the amount of energy each object has.

Energy Quiz – True or False?

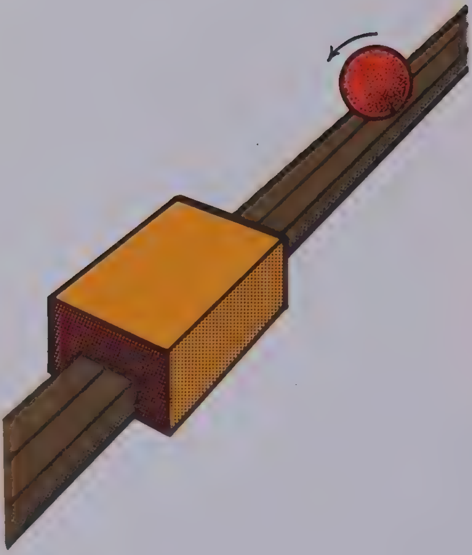
1. The Athabasca Tar Sands contain more oil than the total known world reserves of conventional oil.
2. Coal is no longer of significance as an energy source.
3. It takes less energy to run an electric freezer when it is almost empty than when it is almost full.
4. A microwave oven uses less energy than a conventional electric oven
5. The harnessing of Niagara Falls and the St Lawrence, Columbia and Red Rivers has guaranteed that Canada will always have a cheap supply of electrical energy
6. Electricity is the most efficient way to heat your home.



9.2 Kinetic Energy: Energy of Motion

It should be easy for us to think of many objects which are moving, and as a result of this motion are able to do work. A bulldozer pushing dirt into a pile is a good example, but so is a windmill lifting water from a well, a propellor pulling an aircraft forward, or a generator on a bicycle wheel causing a headlamp to glow. In each case work is being done by a moving object, so we can conclude that the moving object must have energy – energy of motion or kinetic energy, as we call it.

What factors will determine the amount of kinetic energy a moving object has? That is, what factors affect how much work the moving object is capable of doing? Let's do an investigation to find out. To measure an object's kinetic energy, we must measure how much work it can do as a result of its motion. If we use various marbles rolling along a track as our moving objects, we can measure the amount of work they can do by measuring how far each marble can push a small wooden block lying on the track, before coming to rest.



9.3 Investigation: Kinetic Energy

PROBLEM: WHAT FACTORS AFFECT THE AMOUNT OF KINETIC ENERGY A MOVING OBJECT POSSESSES?

MATERIALS:

piece of track
wooden block
marbles of different mass

PROCEDURE:

Place the track on a level table and put the wooden block on the track, about halfway along. After marking the position of the front end of the block with a pencil, roll the lightest marble along the track, allowing it to collide with the block, thereby pushing it forward. Measure the distance moved by the block, and put it back to its starting position. Repeat the same procedure several times, each time increasing the speed of the marble. Next, use marbles of increasing mass, trying to roll each at the same speed, and measure how far each marble pushes the block.

QUESTIONS:

1. What factors determine the amount of kinetic energy a moving object has? How does each factor affect the kinetic energy?
2. The police often do ballistics tests on firearms by firing bullets into a sandbag and measuring the depth to which they penetrate. What do they hope to determine about the bullets in this experiment?

9.4 Gravitational Potential Energy: Energy of Position

The marbles which we rolled along the track in our previous investigation had kinetic energy because they were moving – the faster they move, the more energy they have. But could these marbles be stationary, instead of moving, and have any energy? At first you might think not, since they obviously would be unable to push the block along the track and do work on it. But what if the marbles were stationary at the top end of an inclined track, with the block resting on a flat portion of track at the bottom of the incline? Could the marble then do any work on the block? All we have to do is let it roll down the track. The marble at the top of the track has the potential to do work on the block by virtue of its position; that is, since it is higher than the block, it can roll down the incline and push the block forward when it gets to the bottom. Energy which is stored in this way, for use later, is called potential energy, and since the energy may be released from storage by the downward force of gravity, we say that the marble at the top of the incline has gravitational potential energy.

To try and find out what factors affect the amount of gravitational potential energy an object has, we can do another investigation with the marbles and track.

9.5 Investigation: Gravitational Potential Energy

PROBLEM: WHAT FACTORS AFFECT THE AMOUNT OF GRAVITATIONAL POTENTIAL ENERGY AN OBJECT HAS?

MATERIALS:

2 pieces of track
wooden block
books
marbles of different mass

PROCEDURE:

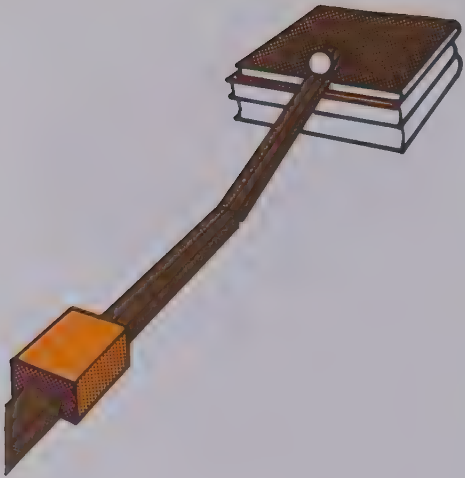
Join the two lengths of track by using a small piece of cellulose tape along the surface of the two sections as they butt together. One half will be flat on the table while the other end can be elevated, using the books.

Place the wooden block halfway along the flat section of track and mark its initial position. Put one book under the elevated end of the track and release the smallest marble from the top end of the track. Measure how far the block is pushed by this marble. Repeat the same procedure, using marbles of increasing mass, released from the same position. Draw a graph of mass versus the distance the block was pushed.

Now, using the same marble each time, place two, three and finally four books under the elevated end of the ramp and in each case measure how far the block is pushed when the marble is released. Draw a graph of vertical height of marble versus distance the block was pushed.

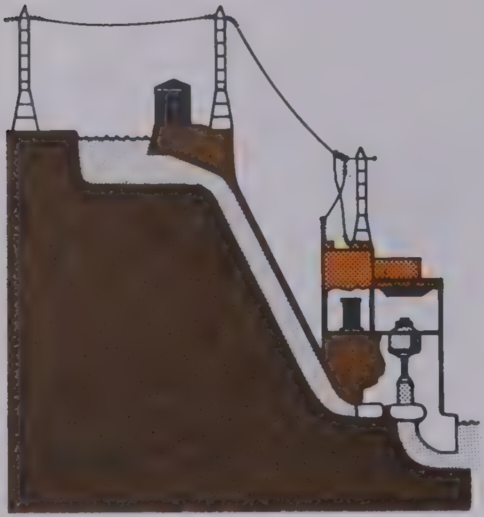
Answers To Energy Quiz

1. *True.* But the difficulty in extracting the oil from the tar sands is immense. Expensive equipment is needed to mine the tar sands and to transport this material to refineries. Transportation of refined oil from Alberta to a market is also expensive. In addition, transportation uses energy so that the efficiency of extracting the oil from the tar sands is quite low.
2. *False.* Canada still has large coal reserves which will be reopened as gas and oil become scarce. New techniques of mining, processing and transporting coal will make coal mining more pleasant, safer and more efficient.
3. *False.* Energy loss through the walls of the freezer is the same regardless of how much is inside. When the door is opened, most loss of energy occurs by the exchange of hot and cold air and since more air would be exchanged by an empty freezer, it will use more energy. Also, more energy is lost by opening the door of an upright freezer than by lifting the lid of a horizontal freezer. Can you explain why?
4. *True.* The microwave oven not only cooks food in much less time than a regular oven but uses only about one-sixth as much electrical energy. Unfortunately, microwave ovens are expensive to produce and purchase.
5. *False.* Energy from moving water provides a large portion of Canada's present needs, but the demand for electricity has been doubling every ten years. All economical sources of naturally falling water are now being used. Remaining hydro sites are too distant from markets and involve flooding large areas of valuable land. Oil and gas for use in thermal plants are rising in cost, so emphasis is now being placed on nuclear generating plants.
6. *It depends.* Electric heaters are 100% efficient whereas gas and oil burners lose energy up the chimney, as well as burning fuel at only about 60% efficiency. However, we must also look at the source of the electrical energy. If it is thermally generated from oil, coal or gas, the generating process will waste about 70% of its energy and electricity will therefore be less efficient. But if it is generated from falling water it is more efficient.



QUESTIONS:

1. What factors affected the amount of work the marble was able to do – that is, the amount of gravitational potential energy the marble possessed when released from the top of the ramp?
2. What effect did doubling the original height of the incline have on the energy of the marble?
3. Choose two of your marbles whose masses are in a simple ratio. Is there any relation between this ratio of their masses and the ratio of their gravitational potential energies when released from the same height?
4. At Niagara Falls, water is diverted from the Niagara River above the falls and allowed to fall down to the level of the lower river through large tubes in a generating station. What type of energy does the water possess just before entering the generating station? As it falls what type of energy does the water begin to acquire?
5. By the time this falling water reaches the bottom of these tubes, it is moving quite fast and is capable of pushing very large and heavy generators and causing them to rotate. What type of energy do these generators eventually produce?



9.6 Conversion of Mechanical Energy: The Pendulum

Our last two investigations have dealt with kinetic energy and gravitational potential energy, both forms of energy which we call mechanical energy. But did each of these investigations deal solely with one type of energy? In the gravitational potential energy investigation, was the block pushed along the track by gravitational potential energy directly? If you think back carefully, you will see that it was kinetic energy which was responsible for pushing the block. The gravitational potential energy that the marble had at the top of the inclined track was converted into kinetic energy as the marble rolled down the track. As the marble moved down the track, its height and hence its gravitational potential energy decreased, while its speed and hence its kinetic energy increased. It seems clear that the marble was gaining kinetic energy at the expense of gravitational potential energy.

Could the reverse of this conversion occur? Could a moving marble roll up a ramp until it had stopped? Of course, the further up the ramp it moved, the slower it would move, so that kinetic energy would be lost as gravitational potential energy was gained. The investigation we will do next employs a common device, the simple pendulum, in which energy is continuously converted from one form to the other.

9.7 Investigation: Energy Conversion

PROBLEM: WHAT CAN WE LEARN ABOUT ENERGY CONVERSION IN A SIMPLE PENDULUM?

MATERIALS:

thread
small mass
retort stand and clamp

PROCEDURE:

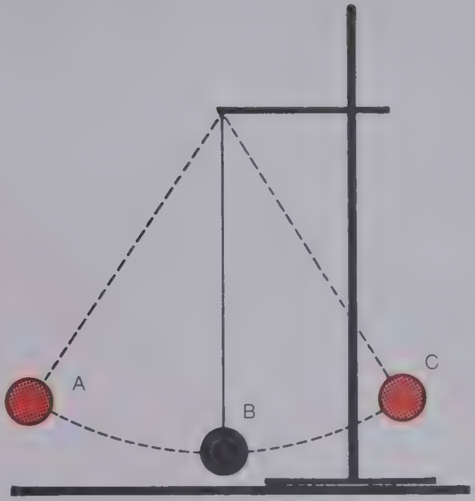
Set up a simple pendulum by suspending the small mass from the clamp on the retort stand with a length of thread. Arrange the length of the thread so that the mass hangs just above the surface of the table. Pull the mass to one side and release it. Observe the motion of the pendulum as it swings from position A to B to C and back again.

At what point(s) does the pendulum appear to be moving at its slowest speed? How much kinetic energy does the pendulum have at these points? At what point does the pendulum appear to be moving at its fastest speed? At what points does the pendulum appear to have the greatest amount of gravitational potential energy? Where is the gravitational potential energy at its minimum?

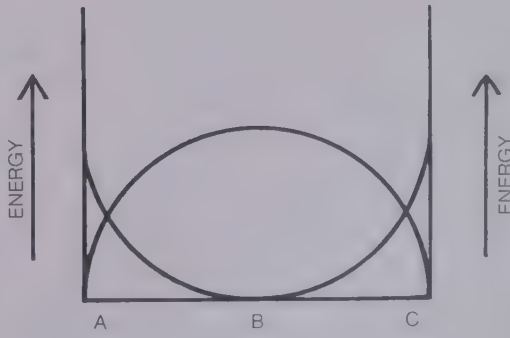
During which parts of the swing is energy being converted from gravitational potential to kinetic? During which parts of the swing is energy being converted from kinetic to potential? Try to determine any point(s) at which the energy is half kinetic and half potential.

QUESTIONS:

1. How should the height of position A compare with position C? Why? Does it?
2. After the pendulum has been set swinging, is any more work done on it? As a result, what should we find regarding the total energy of the pendulum at all points in the swing? The graph at the right shows both the kinetic energy and the gravitational potential energy at all points in the swing of the pendulum. Identify which graph is potential and which is kinetic energy. Also try to draw the graph of the *total* energy of the pendulum.
3. As the pendulum continues to swing, what seems to happen to the relative positions of points A and C? What is actually happening to the total energy of the pendulum?
4. What causes the pendulum to lose energy as it swings?
5. Could you describe other systems, similar to a pendulum, in which energy could be continuously converted from one form into another?
6. Why is it important for a pole vaulter to develop as much speed as he can before planting his pole to jump?



The length of time taken for a pendulum to make one complete swing is called its period. What factors do you think affect the period of a pendulum, and how do they affect it? Perhaps you could devise an experiment to test your hypothesis.



9.8 Chemical Potential Energy: Energy Stored in Matter

The two forms of energy we have been working with are both easy to identify: an object with kinetic energy is moving, and one with gravitational potential energy is located vertically above some other level to which it may fall. There are, however, other forms of energy which are almost impossible to detect visually. When a match is struck we are able to detect both heat and light being produced by the burning match. You may recall from Chapter Eight that both heat and light are capable of doing work and hence contain energy. But where did this heat and light energy come from? It must have been stored in the match, and the process of igniting the match caused it to be converted to heat and light. The substance making up the match must possess energy which can be converted to other forms when the match is ignited. This type of energy, stored in matter, is called chemical potential energy.

The same type of energy is stored in all fuels such as natural gas, kerosene, gasoline, wax, etc. In fact, since food acts as fuel for the human body, chemical potential energy stored in the foods we eat can be converted into heat to keep our bodies warm and also to provide muscular energy for our activities.

Energy and the Density of Car Batteries

The density of the liquid in the cells of a car battery gives an indication of how much energy is stored in it. As the battery discharges, its density decreases.

In a new car battery, all of the cells should have a density of about 1260 kg/m^3. This will drop to about 1220 kg/m^3 in a dead battery. All of the cells should be within 25 kg/m^3 of each other at all times or there is something wrong.

The density of the cells is measured with an instrument called a "hydrometer". It resembles a large eye-dropper about 300 mm long. Battery acid is drawn into it. A little float inside the barrel of the hydrometer sinks to a certain level, depending on the density of the liquid. A scale on the side of the float measures the density.

The energy available from a quantity of matter is given by

$$E = mc^2$$

where m is the mass of the matter; c is the speed of light. This equation, one of the best known in physics, was formulated by Albert Einstein (1879-1955). It shows the equivalence of mass and energy.

9.9 Investigation: Energy in Fuel

PROBLEM: HOW MUCH ENERGY DOES FUEL CONTAIN?

MATERIALS:

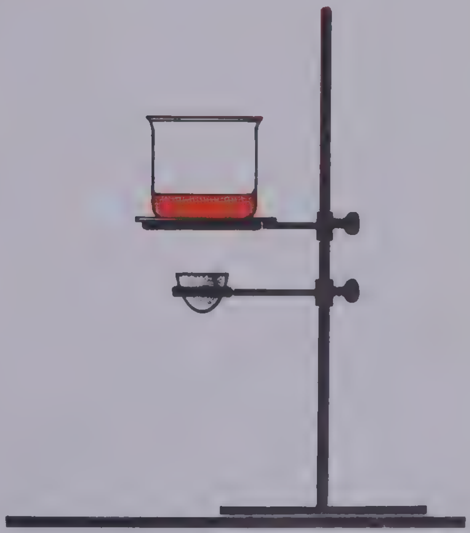
retort stand and ring clamp
250 ml beaker
crucible
alcohol (ditto fluid)
thermometer

PROCEDURE:

Carefully measure out 100 ml of water into the beaker. Pour a small measured amount (2 or 3 ml) of alcohol into the crucible and place it just under the beaker of water on the ring clamp. Measure the temperature of the water. Ignite the alcohol with a match. Stir the water gently until all of the alcohol has burned away. Then once again measure the temperature of the water.

CAUTION:

Liquids other than alcohol may be tested in this same manner, but many are explosive or produce poisonous vapors. Check with your teacher before trying.



QUESTIONS:

1. What is the increase of the water's temperature measured in degrees Celsius?
2. How much heat is gained by the water, measured in joules? Remember, it takes 4.2 J of heat to increase the temperature of 1 g of water by 1°C.

3. How much heat would 1 ml of alcohol produce when burned?
4. Would 1 ml of alcohol actually contain more or less energy than you have calculated? Explain.
5. Small pieces of wood or coal may be used in a similar experiment to measure their energy content, but they are difficult to ignite. Can you suggest a solution to this problem?
6. Food chemists check the energy content of foods by burning them in a closed container called a calorimeter. Why would they use a closed container?
7. When a food chemist says that a chocolate bar contains 420 kJ, he means 420 000 J. If this chocolate bar were burned and all of the heat were captured by 1000 g of water, how much would the temperature of the water rise?
8. Similarly, when you are on a diet, the energy content of the food you eat is limited to a specific number of joules per day. Suppose you are on a 5000 kJ/d diet, and assuming that your body is equivalent to about 60 000 ml of water and nothing else, how much would this energy raise the temperature of your body if completely changed to heat?
9. To keep your body temperature constant, it must have ways of losing heat if the amount of body heat increases, and of gaining heat if the normal production of heat is not enough to keep your temperature up to normal. What are some of these methods?

Nuclear Energy

Nuclear energy is utilized in modern nuclear power stations to produce electrical energy. The tiniest particles of uranium are split into two smaller particles in a process called fission, and a tremendous amount of heat is produced. This heat energy may be used to produce steam, which expands rapidly to push turbines and cause generators to produce electricity.

Although less than 1% of the uranium mined is capable of this fission process, 1 kg of fissionable uranium can produce as much heat energy as about 3 000 000 kg of coal, 1 400 000 *l* of fuel oil or 300 000 m^3 of natural gas.

One of the world's largest nuclear stations, the Ontario Hydro Pickering Nuclear Power Station, built on the shores of Lake Ontario, has the capacity to produce 2 000 000 000 J/s of electrical energy. Since it first began operation in 1971 it has maintained an outstanding record of reliability and safety.

The Energy of the Sun

The sun is a glowing ball of hot, gaslike material, called plasma, about 1 400 000 km in diameter and 149 000 000 km away from the Earth. The surface of the sun is its coolest part, yet it has a temperature of approximately 6000 K and produces heat and light energy at the rate of about 67 000 000 J/s from every square metre of its surface area. This means that the sun pours out energy from its total surface at the rate of 3.5×10^{26} J/s.

Of this staggering total, about one part in one billion falls on the surface of the Earth. If this energy, which we get from the sun for free, had to be purchased at the very reasonable rate of 1¢ for 2 000 000 J (about the cost of buying electrical energy from your local Hydro company), we would have to pay about $60 billion per minute.

The sun produces this tremendous amount of energy by "burning" hydrogen (actually using it up in a process called fusion), so that it loses mass at the rate of 19 800 000 kg/s. This seems to be a tremendous amount, but when we compare it to the total mass of the sun, we find that it possesses sufficient hydrogen to keep shining for about nine billion more years.

9.10 The Energy Crisis: What Can Be Done?

When we think for a moment of the tremendous amount of work that is done in the world in one day, and realize that all of this work must be done at the expense of some form of energy, we begin to appreciate the demand on the world's energy resources. High-powered automobiles, inter-continental jet travel, widespread use of work-saving but energy-gobbling appliances and increased use of the colder climates for human habitation have contributed to an increase in energy usage. The conventional sources of energy, such as coal, crude oil and petroleum products and rapidly moving water, are becoming scarce or overburdened.

Some recent developments have provided hope for success in the energy race, in the following fields:

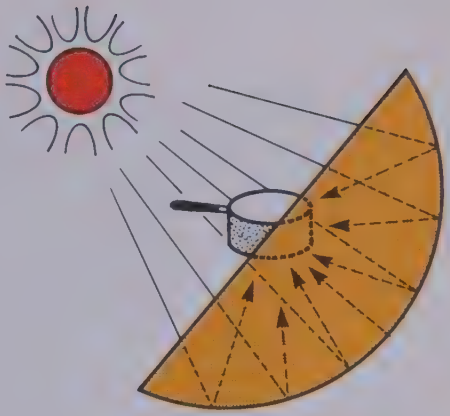
NUCLEAR ENERGY

Some types of matter, which we call radioactive, can be mixed with other types of matter, under the correct circumstances, and result in a nuclear reaction. If properly controlled, this nuclear reaction can produce a tremendous amount of energy by using only a relatively small amount of radioactive matter. The difficulty here, of course, is that the Earth only contains a

limited supply of this radioactive material, which is expensive to find and purify for use in nuclear reactors. Nevertheless many of these reactors are in use throughout the world today and are successful in meeting a share of man's energy demands.

SOLAR ENERGY

For centuries man has been intrigued by the possibility of capturing and using the immense quantity of energy which falls on the Earth's surface every day, in the form of heat and light from the sun. Lenses and mirrors have been used to capture this energy for cooking and heating when the sun is shining, and more recently, solar cells have been developed to convert the sun's energy into electricity. Absence of light at night and on overcast days when the sun is not shining are major drawbacks to relying completely on solar energy. Even though experimental homes have been designed and are operating using only solar energy for all of their requirements, they are extremely expensive.



What can we do while we wait for science and technology to discover the new sources of energy we so desperately need? If we are ever to succeed in this great energy crisis, we must cut down on our energy demands. This challenge is one which faces those of us who are young and will soon inherit a world which may be bankrupt of energy. How many ways can you think of for saving energy?

9.11 Summary

1. Energy may be defined as the ability to do work. Anything which possesses energy can do work and vice versa. The amount of energy an object has may be measured by the amount of work it is capable of doing.
2. Moving objects possess kinetic energy. The amount of kinetic energy an object has depends on its mass, and the speed at which it moves. The greater its mass and the faster its speed, the more kinetic energy it has.
3. Objects lifted up to a height from which they may fall (due to the force of gravity) possess gravitational potential energy. The amount of gravitational potential energy an object has depends on its mass and the height from which it may fall. The greater the height and the greater its mass, the more gravitational potential energy an object has.
4. Mechanical energy, consisting of kinetic and gravitational potential energy, may be converted from one form to another. A falling object loses gravitational potential but gains kinetic energy. A rising object loses kinetic but gains gravitational potential energy.

"While the production of energy is requiring more and more of our capital, manpower and other resources, and is causing environmental problems, our current utilization of energy is so inefficient and wastes so widespread that we could cut the rate of growth by as much as one-half without devising new industrial strategies and at the same time improve the quality of life in Canada

"Lack of attention to conservation in the past, changing energy prices, and the enormous capital costs of energy-supply projects all indicate that conservation can save both dollars and resources

"It is therefore proposed that the federal government adopt a policy of conservation that would have as its primary objectives the promotion of efficiency and the elimination of waste in the utilization of energy."

—Excerpt from a Memorandum to Cabinet Office of Energy Conservation, Department of Energy Mines and Resources, December 4 1974

5. Energy may be stored in matter in the form of chemical potential energy, such as in fuels and foods. This energy may be converted into other forms of energy, often as a result of burning.

6. Since all work must be done at the expense of some form of energy, it follows that the world's supply of energy must be decreasing. In the near future, new sources of energy must be found – such as nuclear or solar energy – to ensure that the world's enormous energy requirements can continue to be met. In the meantime, we must look for ways to restrict the amount of energy we use.

9.12 Further Investigations

1. Discover what each of the following scientists has contributed to the ideas discussed in this chapter.
   (a) Thomas Savery (1650-1715)
   (b) James Watt (1736-1819)
   (c) Thomas Young (1773-1829)
   (d) Gaspard de Coriolis (1792-1843)
   (e) Sadi Carnot (1796-1832)
   (f) James Prescott Joule (1818-1889)
   (g) Wilhelm Daimler (1834-1900)
   (h) Enrico Fermi (1901-1954)
   (i) Sir Christopher Hinton (1901-)
   (j) Hans Bethe (1906-)
   (k) Nikolaus Otto (1832-1891)
   (l) George Stephenson (1781-1848)
   (m) Frank Sprague (1857-1934)
   (n) Wilbur and Orville Wright (1867-1912, 1871-1948)

2. In addition to looking for new sources of energy, scientists today are trying to encourage society to cut down on energy usage and waste. One method of decreasing house-heating energy consumption is by using improved insulation. Fill a metal can with boiling water, cover it with a lid with a hole in it, insert a thermometer into the hole, and measure the time taken for the water to drop from 90°C to 80°C. Repeat, wrapping the can in several thicknesses of newspaper, and again measure the time taken for the temperature to fall the same amount. Try doubling and even tripling the thickness of the insulation. Draw a graph of time versus insulation thickness to show the effect of adding the extra layers of paper.

Energy and the Bicycle

A bicycle rider may be the most efficient of all travellers. According to estimates developed at Duke University, a person riding a bicycle uses less energy per kilogram of body mass per kilometre travelled.

A modern bicycle is efficient for several reasons. First, it uses the body's strongest muscles, the thigh muscles, in a smooth, regular motion. Second, by proper gearing, these muscles can operate at their most efficient speed. Third, frictional forces are reduced by ball-bearing axles, chain drive and large rubber tires. Fourth, modern materials keep the mass of the bike to an absolute minimum, and fifth, the rider travels sitting down, conserving the energy usually used to keep himself standing. These factors make bicycle riding at least five times as efficient as walking or riding in a car.

Here are some data on other travellers. Notice that even riding a horse is more efficient than driving a car.

Mode of Transport	Energy Used J/(kg · km)
bicycle rider	630
salmon swimming	1680
horse walking	2500
person walking	3150
automobile	3400
sea gull	6300
jet plane	6720
helicopter	14700
hummingbird	16800
bee	63000

DUFFERIN & KING
$180 UP
1 & 2-BDRM. APTS.
AVAILABLE
363-1306
NATIONAL
PROPERTY MANAGEMENT
CALL ANYTIME
HEAD OFFICE
267-8554
JANE-DUNDAS
JARVIS-WELLESLEY
BACHELORS $44 WK. UP
1-BEDROOM $60
NEW RENTING
Worth looking into every day.
368-361

More than a third of the heat in a house can be lost through the ceiling. To save heat, up to 15 cm of fiberglass or rock wool may be used over the ceiling.

Cost of a Bath (based on cost of heating bath water at average domestic electricity rates)

Depth of Water (cm)	*Temperature of Water* *Warm 50°C*	*Hot 60°C*	*Very Hot 70°C*
10	6¢	8¢	10¢
15	10¢	13¢	15¢
20	13¢	17¢	20¢
25	17¢	21¢	25¢

The Biomass Institute in Winnipeg has developed a methane digester suitable for Canadian livestock farms. It uses bacterial action on crop and animal wastes to produce methane, which can be burned and its energy used to drive machinery.

9.13 Review

1. Define what we mean by the term energy. List as many objects as you can which possess different types of energy, based on your definition.
2. A Volkswagen and a Cadillac are both parked at the top of a long hill. What type of energy, if any, does each possess? Which has more energy, and why?
3. If they both begin to coast down the hill, what energy conversion takes place, and what type of energy does each have at the bottom of the hill?
4. Assuming that both vehicles arrive at the bottom of the hill at the same time and are moving at the same speed, which has more energy? Why?
5. At this point both drivers apply their brakes to bring the vehicles to a stop, and they both come to rest in the same time and at the same place. Which car's brakes did more work in stopping the vehicle? Which car's brakes exerted more force?
6. The complete burning of 5 ml of kerosene causes the temperature of 150 ml of water to increase by 10°C.
   (a) How many joules of heat would be required to cause this temperature increase in the water?
   (b) What is the energy content of kerosene in J/ml?
   (c) What type of energy does the kerosene contain?
7. What problems are scientists confronted by in trying to utilize nuclear and solar energy to ease the energy crisis?
8. List several ways in which the public can reasonably decrease the amount of energy consumed. How can we best encourage adoption of these measures?

9.14 Instructional Objectives

1. To define energy in terms of the relationship between energy and work, and to state how energy can be measured.

2. To state the conditions necessary for an object to have kinetic energy, and to state the factors affecting the amount of kinetic energy an object has.

3. To state the conditions necessary for an object to have gravitational potential energy, and to state the factors affecting the amount of gravitational potential energy an object has.

4. To describe the conversion of kinetic energy into gravitational potential energy, and vice versa, which occurs

in a pendulum, and to describe other systems in which mechanical energy is converted from one form into another.

5. To determine the energy content of a fuel such as alcohol, and to describe how the energy content of foods and other forms of matter may be determined.

6. To state several reasons why the world is facing a severe energy crisis in the 1970's, to name some alternate sources of energy and describe their potential for success and to suggest ways in which mankind can ease the burden by decreasing energy demands.

9.15 Glossary

chemical potential energy
energy
gravitational potential energy
kilojoule
kinetic energy
mechanical energy
nuclear reaction
pendulum
radioactive
solar energy

The force between particles

10.1 The Particles Have Names
10.2 The Force between Particles
10.3 Investigation: Forces between Soap Particles
10.4 Investigation: Forces between Water Particles
10.5 Force and Distance
10.6 Investigation: Forces between Particles / Temperature
10.7 Forces in Solids
10.8 Investigation: Forces between Particles / Distance
10.9 Forces in Gases
10.10 Investigation: Forces / Gas Molecules
10.11 Kinds of Force
10.12 The Atomic Force
10.13 Investigation: Electric and Magnetic Forces
10.14 Investigation: Electric and Magnetic Forces / Water
10.15 Testing the Atomic Force
10.16 Tearing Water Molecules Apart
10.17 Investigation: Electrolysis of Water
10.18 Summary
10.19 Further Investigations
10.20 Review
10.21 Instructional Objectives
10.22 Glossary

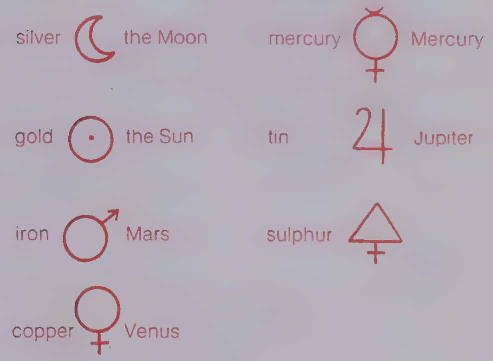
10.1 The Particles Have Names

We know from our investigations that matter is built from billions of tiny particles, called atoms by the Greeks. There are 92 different kinds of atoms found in nature, and fourteen more, so far, that have been manufactured. When a substance is made from only one kind of atom, it is called an element. There are 106 different elements, one for each atom. Some elements have common names, such as copper, iron, lead, mercury, oxygen, sulphur and uranium, but others, more difficult to find, have less well-known names, such as scandium, lutecium and gadolinium.

But there are more than 106 different substances. Combinations of particles can form to produce many substances. For example, an oxygen atom can hook up to two hydrogen atoms to form a molecule of water. If you can get several billion of these combinations, or molecules, together, you will have a glass of water. Different combinations of the same atoms produce different molecules and different substances. If two oxygen atoms and two hydrogen atoms join together, a molecule of hydrogen peroxide will form. That one extra atom of oxygen produces a compound that will bleach your hair instead of just washing it.

There is an unlimited number of combinations of 106 elements, which form an unlimited number of molecules, which group together to form an unlimited number of compounds. As a group, the elements and compounds are known as pure substances. Even then, there are still many materials to go. Many mixtures of elements and compounds are recognized as separate substances, such as wood, brass, bronze, solder and meat.

The alchemists had symbols for the elements, including:



Can you see why certain elements were associated with the various planets? Astronomers still use these symbols.

In 1803, John Dalton published his "atomic theory":

1. All matter is made up of small, indestructible particles called atoms
2. Atoms of any element are alike
3. Atoms combine with other atoms to form molecules.
4. Atoms do not lose their identity in chemical reactions.

Although Dalton had rediscovered atoms, he had no idea what the force between atoms could be. This question was not decided for another 100 years.

10.2 The Force between Particles

In the previous section we introduced you to atoms and elements, molecules and compounds. A bunch of iron atoms make a block of iron; oxygen and hydrogen atoms stick together to make a glass of water. But what force is doing all this? Is the same force responsible for holding together an iron oil tanker and the water it rides in? How can the force that is so strong in one case be so weak in the other? What is it about the atoms that hooks them together so strongly in one case and so weakly in another?

More importantly, can we find this force acting on a large scale? Does the force between atoms act between larger pieces of matter? Do large pieces of matter tend to stick together, due to some atomic force, or do they just sit there? Perhaps a look at soap solutions and water drops can give us the answers to these questions.

In 1814, Berzelius (1779-1848) suggested the present system of symbols, using the first one or two letters of the name of the element (in some cases, the Latin name)

hydrogen	H
helium	He
carbon	C
oxygen	O
silver *(argentum)*	Ag
gold *(aurum)*	Au
copper *(cuprum)*	Cu

10.3 Investigation: Forces between Soap Particles

PROBLEM: WHAT EVIDENCE IS THERE THAT THERE ARE FORCES BETWEEN MOLECULES IN A SOAP SOLUTION?

MATERIALS:

5 cm loop of wire
short piece of thread
250 ml beaker of soap solution
funnel

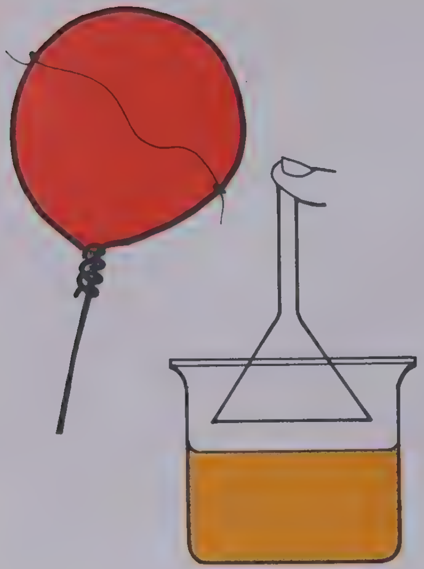
PROCEDURE:

Tie the thread so that it hangs loosely from one side of the loop of wire to the other. Dip the loop in soap solution. Break the soap film on one side of the thread and then on the other. Repeat in the opposite order.

Hold your finger over the end of the funnel and dip the big end into the soap solution. Raise it to eye level, then release your finger. Describe what happens to the soap bubble.

QUESTIONS:

1. Explain why the thread moved in the first part of the investigation.
2. Explain why the soap bubble moved in the second part of the investigation.
3. Is there attraction, repulsion or no force at all between the various molecules in a soap solution?



The soap film should take a shape which covers the least possible area. Does it do this?

10.4 Investigation: Forces between Water Particles

PROBLEM: DO WATER DROPS EXERT FORCES ON ONE ANOTHER OR ON OTHER MATERIALS?

MATERIALS:

3-10 cm squares of paper, wax paper, aluminum foil
eyedropper

PROCEDURE:

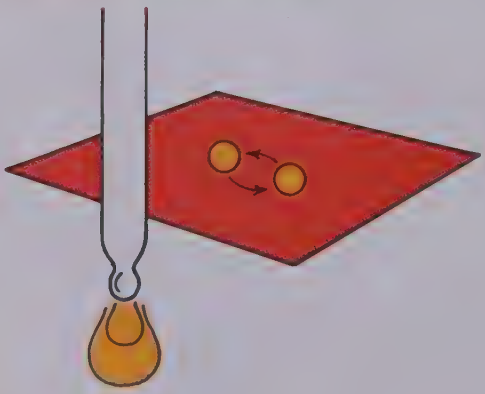
Put drops of water on the three materials. Does the water show any signs of being attracted or repelled by any of them?

Put drops of water on the wax paper. Push them together with the eyedropper. Do they show signs that they attract or repel one another, as they meet?

Draw a picture of a water drop sitting on the wax paper as seen from the side. Can you explain its shape? Does it seem to have anything in common with a balloon?

Try to make both large and small drops of water with the eyedropper by squeezing slowly and quickly. Can you explain why there is a maximum size for a water drop? What would it have to do with the force between water molecules?

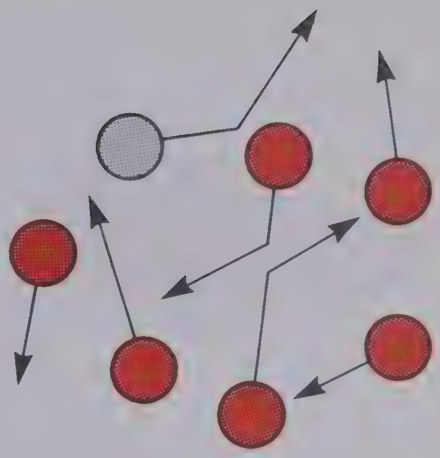
What happens if you try this experiment with alcohol? Or with water and alcohol drops? Or with a little detergent mixed with the water?



10.5 Force and Distance

Some forces depend on distance. As two bar-magnets are brought closer together, the force of attraction between them increases. It is greatest when the two magnets touch. In our last experiment, water drops seemed to attract one another, but only when they were very close together. Could this be the same kind of thing happening?

Inside the water drop, there must be similar forces between water molecules, holding the drop together. Does this force depend on the distance between molecules? Does this force increase as the distance between molecules decreases? How could we make the distance between molecules change or measure the forces?



Perhaps temperature is the answer. We know that cold water expands as it is heated. The slow-moving molecules speed up, bounce off each other and move further apart. The distance between molecules has been increased.

Is hot water as strong as cold water? In the next investigation, you can compare the strengths of hot and cold water by measuring the sizes of water drops from an eyedropper.

10.6 Investigation: Forces between Particles / Temperature

PROBLEM: DOES THE FORCE BETWEEN WATER MOLECULES DEPEND ON THE TEMPERATURE OF THE WATER?

MATERIALS:

250 ml beaker of hot water	eyedropper
250 ml beaker of cold water	10 ml graduated cylinder

PROCEDURE:

Fill the eyedropper with the coldest water you can get and slowly put 100 drops into the graduated cylinder. Record the volume of 100 drops and calculate the volume of one drop.

Repeat with hot water to find the volume of 100 drops and to calculate the volume of one drop.

QUESTIONS:

1. As you squeeze, the water drop grows and grows and hangs down from the end of the dropper. Each water molecule is hanging from the one above it. The critical point is where the water leaves the dropper. The water is passing through the narrowest part of the dropper and fewer molecules are available to support those hanging down. If the force between water molecules decreases, these molecules will not be able to support the growing drop and it will fall. Which kind of water produced the largest drops?
2. Which temperature produced the greatest force between water molecules?

How does this experiment work with alcohol?

The relationship between the length of an elastic object and the force acting on it is known as Hooke's Law. It is almost the same for every stretched or squashed object, from rubber bands to bedsprings to steel girders in office buildings.

3. In which drops were the water molecules closest together?
4. What could this investigation indicate about the connection between the force between water molecules and the distance between them?
5. Did the last experiment indicate anything about the relationship between force and the distance between water drops?

10.7 Forces in Solids

The force between water molecules is strong enough to hold a small drop together, but not strong enough to hold a beaker of water in one piece. Tilt the beaker and the water flows out. But freeze the water; turn it into a solid. Now things are different. A beaker of frozen water, an icicle, a snow drift – all these solids hang together in one piece. Still, solid water is a weak substance compared with some solids. A steel piano wire, 1 cm in diameter, can support almost 25 000 kg, about 25 regular size cars, hanging from it. The force between these atoms must be enormous, in comparison with water.

Does the same kind of force act in solids as in liquids? Does it depend on the distance between particles? Does it then depend on the temperature of the material? In our investigation, we look at the forces between rubber molecules for some answers to these questions.

10.8 Investigation: Forces between Particles / Distance

PROBLEM: DO THE FORCES INSIDE A RUBBER BAND DEPEND ON THE DISTANCE BETWEEN MOLECULES?

MATERIALS:

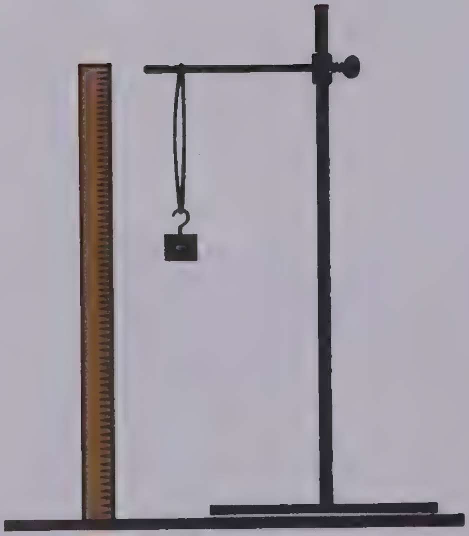
rubber band
masses
tape
metre stick

PROCEDURE:

Attach one end of a rubber band to the edge of the desk or to a retort stand. Measure its length. Hang masses on the end of the rubber band until it is about twice normal size. Choose the size of the masses so that you have at least five measurements of mass and length. Use this information to draw a graph of length versus mass.

QUESTIONS:

1. As the length of the rubber band increases, what should happen to the distance between molecules?
2. When the mass hanging on the end of the rubber band is increased, what must happen to the force between molecules to hold up this new mass?
3. Does the force between rubber molecules seem to increase or decrease as the distance between them decreases?
4. How do rubber forces act compared with water forces?



10.9 Forces in Gases

Are there forces between gas molecules? If you move your hand slowly through the air, it seems effortless. Now put your hand out of a moving car (but not very far out) and feel the air against your hand. Or go out in a 50 km/h wind, if you dare! Air molecules can appear to exert a considerable force, under the right conditions.

Imagine a beaker of air sitting on the desk in front of you. Is it pushing on anything? If you try to put your hand in the beaker, does it resist? Imagine trying it, or go ahead and really try it.

If you were at the bottom of the ocean, you would certainly feel the extra force of the water pressing in on you. Here on the land, we are still on the bottom of an ocean – an ocean of air. It is pressing down on us from above in just the same way. We don't notice it, but it is there. In the next investigation, you will see just how great the force is between air molecules.

In this investigation, don't forget that we are all living underneath a blanket of air, at least 100 km thick, pushing down on us.

10.10 Investigation: Forces / Gas Molecules

PROBLEM: DO FORCES ACT BETWEEN MOLECULES OF A GAS? DO THE FORCES DEPEND ON THE DISTANCE BETWEEN PARTICLES?

MATERIALS:

syringe with end plugged

PROCEDURE:

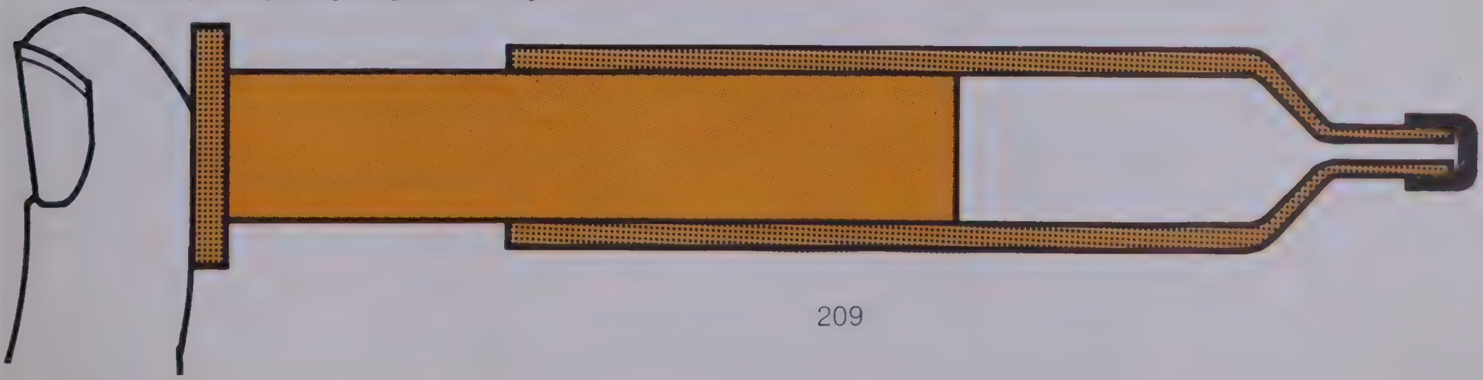
Push in the plunger on the syringe, compressing the air inside. Can you feel it pushing back? Push harder. Does the air push back harder? Release the plunger and see if it returns to its original position. Did you lose much air? Try pulling the plunger out. What happens? Remember that there is air outside the syringe as well as inside it.

Of course, if you push too hard, you can squeeze some air out of the syringe. You might be able to hear it leave. We would rather keep all the air inside.

QUESTIONS:

1. As the air was compressed, did the force increase or decrease? What does this tell you about the force between air molecules?
2. While air molecules are small, they certainly have some size. How does this experiment show you this?
3. If there was no air in the syringe, what would prevent you from pulling the plunger out? Try it.

If your teacher agrees, try this investigation with water in the syringe. What does this tell you about the force or distance between water particles? What does it tell you about water pistols?



The force between iron atoms is sometimes attractive and sometimes repulsive. Try to break an iron bar by pulling on its ends. The attractive force between particles holds it together. Now hit one iron bar with another. They bounce apart. The iron atoms repel one another.

10.11 Kinds of Force

We have seen some of the forces acting between the molecules of solids, liquids and gases. In solids, the forces hold the molecules tightly together to prevent them from moving too freely. In liquids, the forces are not so strong. They are able to hold small numbers of molecules together, as in a drop of water, but cannot hold a glass of water together. In a gas, the forces are there, but do not help much to keep the molecules together.

Can we identify these forces? What properties must these forces have? Have you ever observed these forces?

10.12 The Atomic Force

The force that acts between atoms and molecules should have the following properties:

1. It must change with distance. This happened in most of our investigations.
2. It must sometimes be a repelling force and at other times an attracting force. The particles of gases repel one another; the atoms of solids attract to hold them together.
3. It must sometimes be strong and at other times weak. Consider the large forces acting between iron atoms and the much weaker forces between rubber molecules. Unless a force has these properties, it cannot be our atomic force.

Can you think of a case where liquids repel as well as attract?

Could this force be the force of gravity? The Earth, a very large object, attracts all nearby objects, such as people, textbooks, falling apples, the Moon or all the various space satellites in orbit around it. Large objects are pulled with a large force, smaller ones with a smaller force. If the Earth were smaller, say the size of the Moon, its force of attraction would be smaller. If the Earth and all these other things were reduced to atomic size, the force of gravity would still be there, but it would be reduced to an insignificant amount. The force of gravity varies with distance. The further you travel away from the Earth, the less gravity pulls back on you.

Newton was the first to realize that the force of gravity of the Earth makes falling objects such as apples accelerate and, at the same time, keeps the Moon in orbit around the Earth. He was even able to find the equation to calculate the size of the force. On the other hand, neither Newton nor any other scientist has been able to explain why there is gravity or exactly what produces it. It exists, and that is all we know.

On the other two points, the force of gravity is in trouble. For instance, it only attracts and never repels. This alone rules it out as the atomic force. The size of the force is also a problem. It is too small. It is only noticeable when there is a giant object like the Earth to attract you. But don't discard the force of gravity. It is the force which controls all the large objects in the universe, guiding moons and planets and comets and space probes and suns and galaxies as they travel through space and time.

We must look elsewhere for the atomic force. Perhaps you can think of some forces which may have all the right properties.

10.13 Investigation: Electric and Magnetic Forces

PROBLEM: WHAT ARE THE PROPERTIES OF ELECTRIC AND MAGNETIC FORCES?

MATERIALS:

vinyl and acetate strips
glass and ebonite rods
wool and cotton cloths
fur and silk
strong magnets
iron filings
paper clips
copper shot
zinc dust

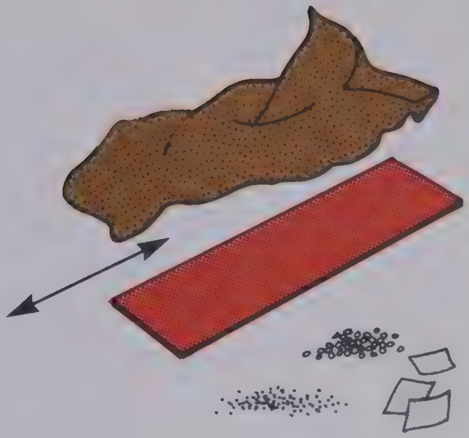
PROCEDURE:

Rub the vinyl with the wool cloth to charge it. See if this electric force will affect some tiny pieces of paper, the iron filings or small pieces of any other material. Try as many different things as you can (brick dust, sand, dust, tiny pieces of a rubber eraser). Repeat this investigation with the magnet. Compare your results in a large chart.

Charge two vinyl strips, hold them lightly at their ends, and slowly bring them together. What kind of force acts? Does it depend on distance?

Charge an acetate strip with the cotton cloth and bring it near a charged vinyl strip. What kind of force acts here? What is the rule for the force between charges? Rub the glass rod with silk and the ebonite rod with fur. Can you tell whether they have the same charge as the acetate or the vinyl?

Bring various combinations of North and South magnetic poles near one another. What kinds of forces act? How do these forces change with distance? What is the rule for the force between magnetic poles?



The two kinds of charge are called positive and negative. Which of these two rules works for charges?

1.	*positive*	*negative*	*neutral*
positive	repel	attract	attract
negative	attract	repel	attract
neutral	attract	attract	no force

2.	*positive*	*negative*	*neutral*
positive	attract	repel	repel
negative	repel	attract	repel
neutral	repel	repel	no force

10.14 Investigation: Electric and Magnetic Forces / Water

PROBLEM: DO ELECTRIC AND MAGNETIC FORCES ACT ON A STREAM OF WATER?

MATERIALS:

vinyl and acetate strips
cotton and wool
strong magnets

PROCEDURE:

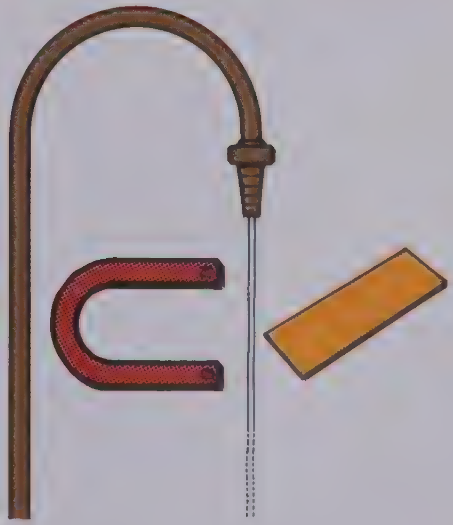
Adjust a water tap so that a fine, continuous stream of water is produced. Test the stream of water by bringing charges, both positive and negative, and the magnet, using both North and South poles, near it. Construct a chart for your observations.

QUESTIONS:

1. According to these results, is the atomic force more likely to be electric or magnetic? Explain.
2. According to your observations, which of the following must be present on water molecules: positive charges, negative charges, North poles, South poles?

Do water molecules act like little magnets, with poles on either end?

Or like little charged strips, with a positive charge on one end and a negative charge on the other?



3. Could one molecule have one kind of charge or pole and other molecules have the other kind of charge or pole? Explain.
4. Is a water molecule like a magnet, with a North pole on one end and a South on the other, or like a plastic strip, with a positive charge at one end and a negative at the other?
5. Remember the properties of the atomic force. Do electric and magnetic forces change with distance? In what way?
6. Do electric and magnetic forces attract and repel? Under what conditions?
7. Are these forces strong enough to hold matter together? How do they compare with the force of gravity? (A little magnet can pick up a paper clip, even though the whole Earth is pulling down on it.)
8. An apple on a tree does not normally attract other objects, like paper clips, to it. Depending on what the atomic force is, what does this tell you about the number of positive and negative charges in it, or the number of North and South magnetic poles in it?
9. If you had to choose between the magnetic or electric force as the atomic force, which one would you choose? Why?

10.15 Testing the Atomic Force

Of all the forces we have tested, the one which most closely fits our requirements for the atomic force seems to be the electric force. It acts on almost every material tested, it can attract or repel, it can be quite a large force as well as a small one. The magnetic force is too specialized – it acts on only a few materials.

If it is the electric force which holds matter together, then we should be able to make use of the same force to tear matter apart. If a positive particle is stuck to a negative particle, then bringing a large positively-charged object near should attract the negative particle and repel the positive one. If the forces are strong enough, the molecule should split into its parts, charged atoms, or as they are called, ions.

The atomic force we are talking about here is the force between atoms or molecules. It operates when one particle approaches another. But what happens inside atoms? Are there different pieces inside? If so, what force holds them together? Is it the electric force, or one of the others, or some entirely new force?

10.16 Tearing Water Molecules Apart

Water is one of the simplest materials to use in such an investigation. An electric power supply can give us a powerful electric force to use on water molecules. If you examine such a power supply, you will see both positive and negative terminals. Any object, such as a copper wire, connected to the positive terminal, will become positive. Objects connected to the negative terminal become negative. These terminals are usually labelled or are color-coded, red for positive and black for negative. If a wire lead from each terminal is placed in the water, any charged particles in the water will be attracted to one terminal, and repelled by the other. All the negative ions will travel to one terminal or electrode, and all the positive ions will travel to the other electrode. This process is speeded up considerably if a material such as ordinary washing soda is dissolved in the water.

10.17 Investigation: Electrolysis of Water

PROBLEM: CAN ELECTRIC FORCES TEAR MOLECULES APART?

MATERIALS:

electrolysis apparatus
solution of washing soda (sodium carbonate) in water
6-V power supply and leads

This experiment can also be done with a little acid added to the water instead of washing soda

PROCEDURE:

Set up the electrolysis apparatus, fill it with the washing-soda solution, connect the leads from the positive and negative terminals of the power supply to the electrodes on the electrolysis apparatus and turn on the power. Bubbles of gas should appear at both electrodes and collect in the two test tubes. Carefully record which electrode is made positive and which is made negative by the power supply. Estimate how much gas is collected in each test tube by marking the level of gas in each tube and then filling it with water at the end of the experiment to that mark. The volume of water then tells you the volume of the gas. Test each tube with a burning splint. Remove a tube, letting the remaining water run out, then insert a burning splint. If it is oxygen gas, the splint will momentarily glow brighter; if it is carbon dioxide, the splint will go out; if it is hydrogen gas, there will be a small explosion. Briefly, this is what you are to do:

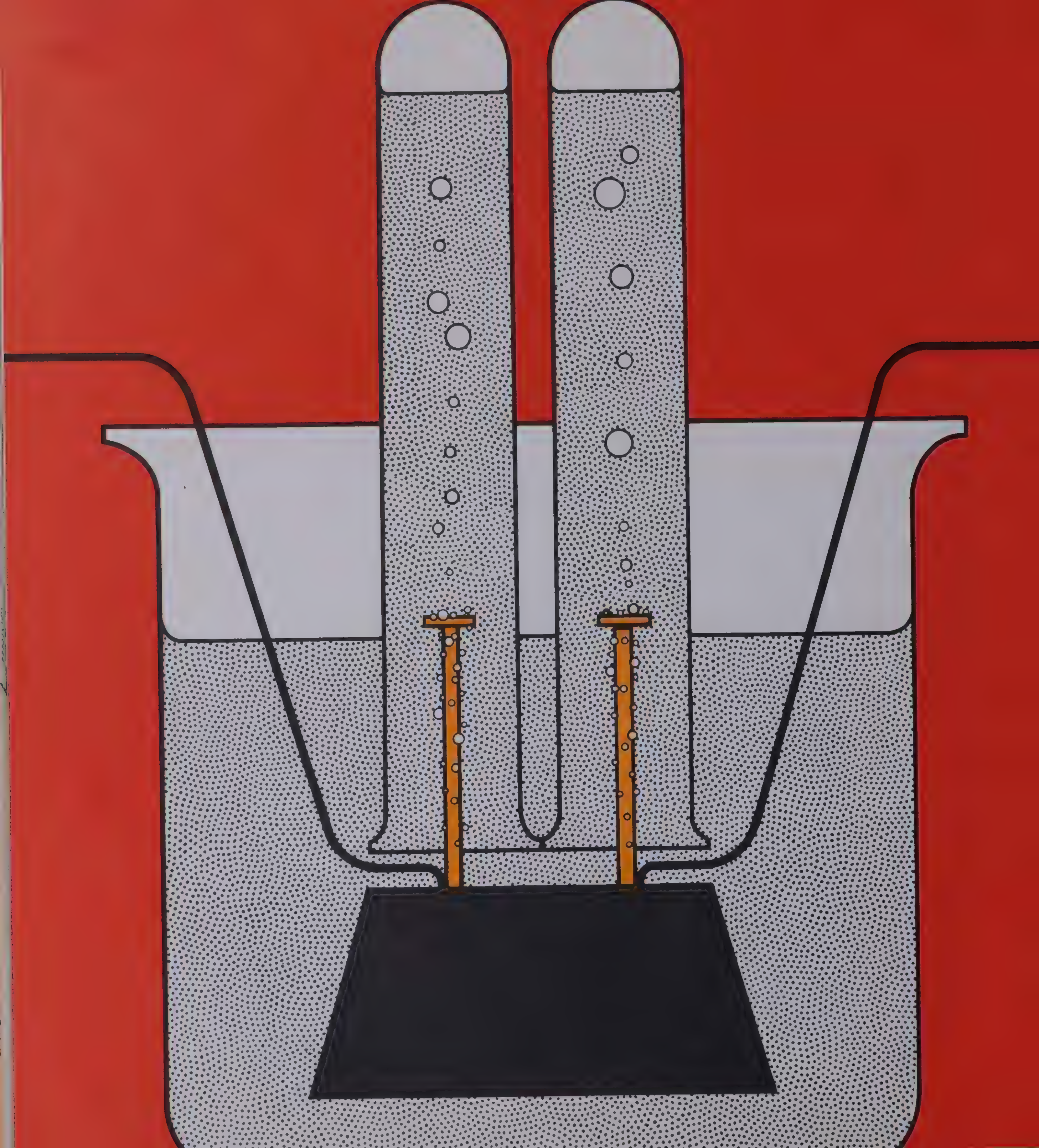
1. Collect gas for 20-30 minutes
2. Mark level of gas on test tubes
3. Test for type of gas in each test tube
4. Measure volume of gas in each test tube

Ideally, the two electrodes should be made from some practically inert substance like platinum, so that they will not take part in the chemical reaction

There are, of course, more than three gases that might appear in this investigation. Our burning-splint test is only an indication of the nature of the gas. With a greater knowledge of chemistry, you could more positively identify these gases

QUESTIONS:

1. What charge must the ions (charged atoms) which travel to the positive terminal have?
2. What charge must the ions which travel to the negative terminal have?
3. What gas collects at the positive terminal? What charge must its ions have?
4. What gas collects at the negative terminal? What charge must its ions have?
5. Did the same amount of gas collect at each terminal? Explain. What might this mean about the size or mass or numbers of gas particles collected?



6. We cannot prove it with our simple experiments, but it turns out that any volume of a gas, no matter what it is, contains the same number of gas molecules as the same volume of any other gas. Each of these contains the same number of molecules: 10 ml of oxygen, 10 ml of hydrogen and 10 ml of nitrogen gas. If this is true, what does our experiment tell us about the number of each kind of gas molecule produced?
7. Since these gas particles are produced as water molecules are torn apart, what is your best estimate of the number of various gas atoms making up each water molecule?

10.18 Summary:

1. There are about 106 simple particles of matter, called atoms.

2. Substances made from a single kind of atom are called elements.

3. Simple combinations of different kinds of atoms can form and are called molecules.

4. Substances whose molecules are all identical are called compounds.

5. Pure substances are either elements or compounds.

6. Forces act between atoms to hold molecules together, between atoms and molecules to hold large blobs of matter together, and even between large blobs of material. The same force acts when gas molecules repel one another or a rubber band contracts. In each case, it is the electric force between positive and negative charges which is acting.

7. Unlike electric charges attract, like charges repel.

8. When the charges are closer together, the electric force is greater.

9. Unlike magnetic poles attract, like magnetic poles repel.

10. As poles are brought close to one another, the magnetic force increases.

11. Water molecules are normally neutral, but act as if they have both kinds of charges in them.

12. Water molecules can be broken into positively-charged hydrogen ions and negatively-charged oxygen ions. Twice as many hydrogen as oxygen ions are produced, suggesting that water molecules contain two hydrogen for every oxygen atom.

Atoms have been imagined as tiny elastic spheres, point particles with no size whatsoever, little blobs with spikes and hooks, miniature Earths with magnetic poles, triangles, hexagons, pentagons and so on. In 1897, Sir J. J. Thomson's atom consisted of tiny negative particles, the "electrons", imbedded in a blob of positive charge. By 1911, Baron Rutherford had proposed the "solar system atom". The positive charges were carried by other particles, the "protons", and these were all concentrated in the center or "nucleus" of the atom. The electrons were in orbit around the nucleus like planets in orbit around the sun. A short time later, Niels Bohr proposed that these electrons could only have certain specified orbits, producing "shells" of electrons around the nucleus. In 1925, Prince Louis de Broglie startled the scientific world by suggesting that a moving electron might have more in common with a wave, like the ripples on a pond, than with a particle, like a raindrop. His picture of the atom consists of a nucleus surrounded by clouds of various sizes and shapes.

10.19 Further Investigations

1. Make a wire loop and some soap solution. Make a loop of thread, with two pieces of thread tied to it, one on each side. Tie the two pieces to the wire loop. Dip in soap solution. Break the film inside the loop of thread with a pin. What happens? Make other shapes with the thread and try to predict what will happen when parts of the film are broken.
2. Get some capillary tubing (glass tubing with a very fine hole in the middle). Hold it vertically in a beaker of water and watch the water climb up inside it. There must be forces between the glass and the water. What happens if you use water at different temperatures? Measure the height of the water each time. What does this tell you about the forces? Use different liquids such as alcohol or mercury (if your teacher approves).
3. Squeeze two perfectly clean microscope slides together very carefully. Now try to get them apart without breaking them. Explain why this happens if you can. Have you ever noticed this effect happening in other situations?
4. Are drops of water the same size as drops of alcohol? Measure and find out. What does the data tell you about the forces involved?
5. The force of gravity makes objects accelerate downwards when they are dropped. Which falls fastest, a rubber stopper, a lead mass or a penny? Drop them from the same height at the same time. Now try a stopper and a piece of paper. Why is this different? Crumple the paper into a small ball and try again. Do all objects accelerate at the same rate due to gravity? Would they do so on the Moon?

10.20 Review

1. Describe the difference between an atom and an element.
2. Describe the difference between a molecule and a compound.
3. Describe the difference between an atom and a molecule.
4. If you drop a steel ball-bearing onto a thick steel plate, it will bounce back – almost to the original drop height. A steel wire can support hundreds or even thousands of kilograms. What basic information about the forces between steel particles do these examples provide?
5. What should happen to the breaking strength of a steel wire as you heat it? Explain.
6. (a) Give two examples of forces which sometimes attract and sometimes repel.
   (b) Give one example of a force which only attracts.
   (c) Give one example of a force which only repels.

7. Water molecules act as if they are positive at one end and negative at the other. What happens inside a stream of water when a negatively charged object is held nearby?
8. In the electrolysis apparatus, the hydrogen gas collects near the negative electrode and the oxygen gas near the positive electrode.
    (a) What charge do oxygen and hydrogen particles have before they touch their electrodes?
    (b) What charge do these particles have after they touch their electrodes? Explain.

10.21 Instructional Objectives

1. To define and distinguish between atoms, molecules, elements and compounds.

2. To describe the properties of electric, magnetic and gravitational forces that distinguish them from one another and make them choices for the force between atoms.

3. To describe the properties of the force between atoms: how it depends on temperature, distance, type of matter, state of matter.

4. To explain how water is reduced to oxygen and hydrogen, using the particle motion theory and electric forces.

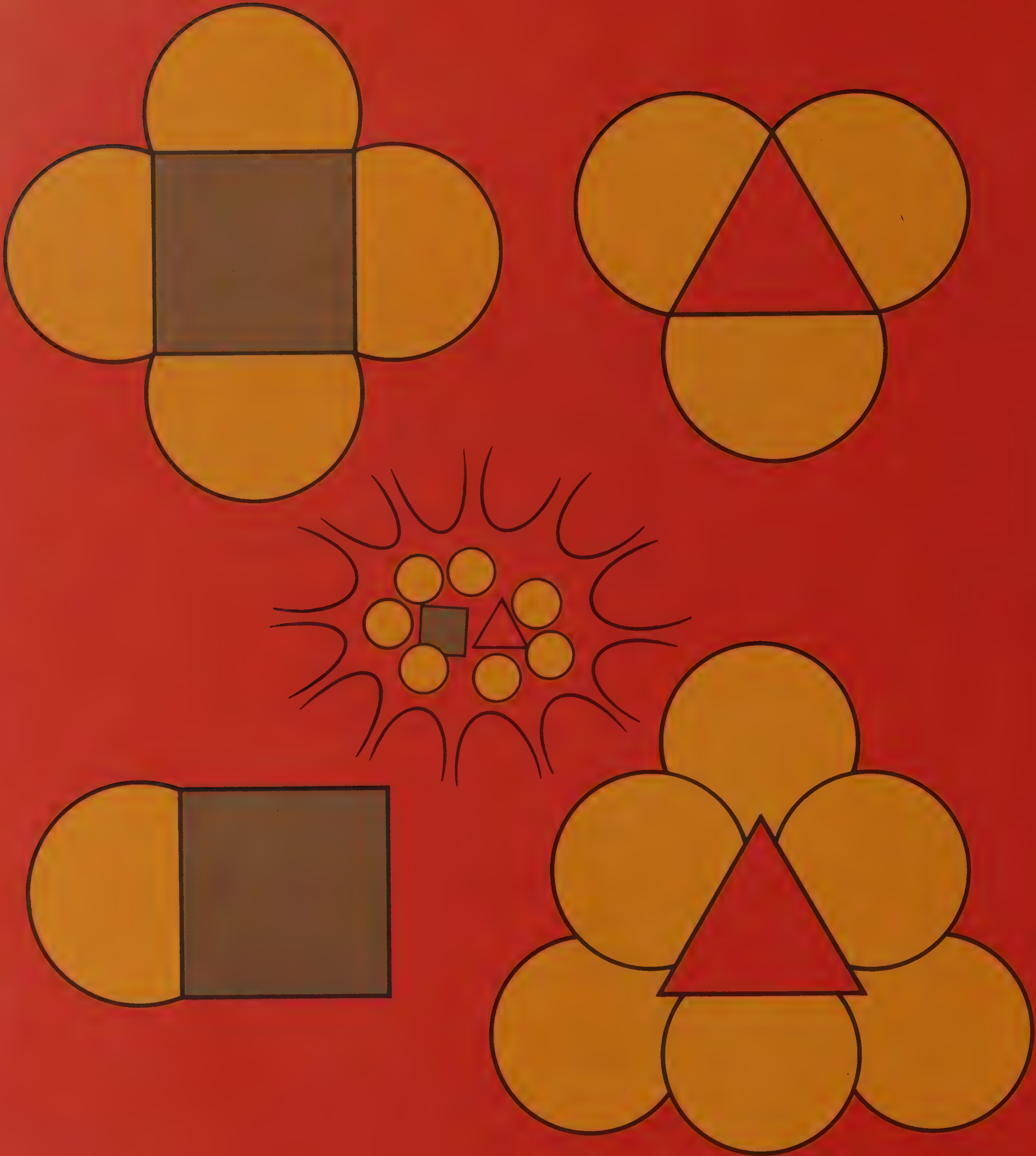
Atoms were once considered to be the basic particles of matter, until they were found to be constructed of simpler particles: the electron, proton and neutron. Now the list of elementary particles is lengthening, with the discovery of positrons, anti-protons, anti-neutrons, neutrinos, mesons, delta particles, sigma particles and so on. New theories now attempt to find even more elementary particles. One promising theory suggests that three particles, called "quarks", and their antiparticles may have all the properties necessary to construct all the heavy elementary particles.

10.22 Glossary

atmospheric pressure
atom
atomic force
attract
compound
electric force
electrode
electrolysis
element
magnetic force
molecule
repel

Reactions between particles

11.1 Physical and Chemical Reactions
11.2 Investigation: Chemical Reactions
11.3 A Theory for Chemical Change
11.4 Investigation: End-Product Amounts
11.5 Rate of Reaction
11.6 Investigation: Reaction Rate / Temperature
11.7 Investigation: Rate / Surface Area
11.8 Investigation: Reaction Rate / Concentration
11.9 Investigation: Rate / Pressure
11.10 Rate of Reaction: Summary
11.11 Oxidation
11.12 Summary
11.13 Further Investigations
11.14 Review
11.15 Instructional Objectives
11.16 Glossary



11.1 Physical and Chemical Reactions

When frozen water melts or liquid water boils, their molecules do not change very much. They might move faster or get further apart, but they each still contain the same number and kind of atoms. In a solid, the molecules are close together and attract each other strongly. In a liquid they are usually slightly further apart and attracted less strongly. In a gas they are far apart and only affect one another when they collide. Changes of state, and other reactions where molecules remain the same, are called physical reactions.

When a piece of wood is burned, the molecules of the burnt wood are quite different from the molecules of the unburnt wood. This is one example of a chemical reaction. In chemical reactions, molecules are changed. Sometimes they break up into smaller molecules, or trade atoms with other molecules, or just rearrange the atoms they already contain into new combinations.

We cannot see these atoms changing places, but it is our best explanation so far for the many changes that we do see. Perhaps a new substance will have a different color, or form crystals with a new shape or be a gas instead of a solid. All these changes must be explained by our atomic theory.

11.2 Investigation: Chemical Reactions

PROBLEM: WHAT ARE THE PROPERTIES OF CHEMICAL REACTIONS?

MATERIALS:

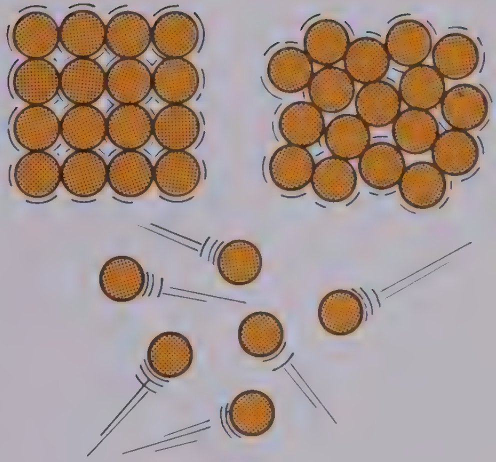
10 ml potassium iodide solution
10 ml lead nitrate solution
ammonium dichromate
10 ml copper sulphate solution
10 ml sodium hydroxide solution
3 test tubes

PROCEDURE:

Pour 10 ml of potassium iodide solution into one test tube and 10 ml of lead nitrate solution into another test tube. Pour the contents of one test tube into the other. Describe the contents of each test tube before and after mixing. How can you tell a chemical reaction has taken place?

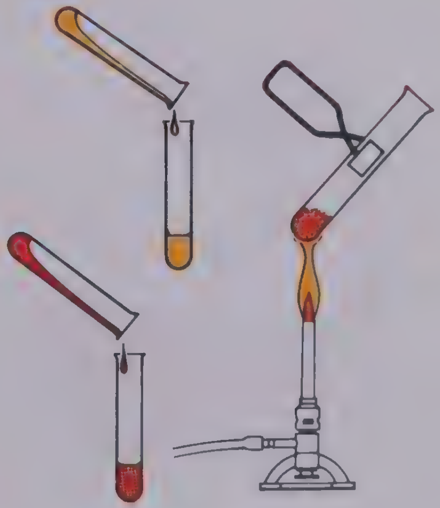
Put one spoonful of ammonium dichromate in a clean, dry test tube. Heat carefully. As above, describe the contents of the test tube before and after, and tell why you think a chemical reaction has occurred.

Pour 10 ml of copper sulphate solution into one test tube and 10 ml of sodium hydroxide solution (be careful with this substance) into another. Mix them together. Describe what happens.



Some physical reactions are
- dissolving
- crystallization
- freezing
- melting
- boiling
- condensation
- evaporation
- sublimation

Some properties which change in chemical reactions are
- color
- transparency
- solubility
- state (solid,liquid,gas)
- temperature
- volume



11.3 A Theory for Chemical Change

The previous investigation does not help very much to explain what is actually happening during a chemical reaction. Color changes turn out to be unexpectedly difficult to understand. Other kinds of observations can be made though, that lead us to a particle theory. What happens to mass during a chemical reaction, or to temperature, or to volume? These kinds of measurements will be made in the following investigations.

11.4 Investigation: End-Product Amounts

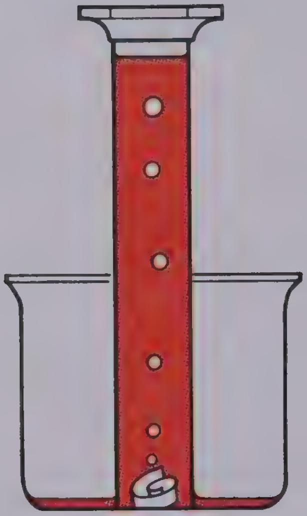
PROBLEM: IN A CHEMICAL REACTION, DOES THE AMOUNT OF END PRODUCT DEPEND ON THE AMOUNT OF THE ORIGINAL SUBSTANCE THAT REACTS?

MATERIALS:

2 strips magnesium ribbon, 2-10 cm long
dilute hydrochloric acid
100 ml graduated cylinder
250 ml beaker

PROCEDURE:

Each team will receive a strip of magnesium ribbon from 2 to 10 cm long. Record the exact length of your strip. Fill a graduated cylinder right to the brim with dilute hydrochloric acid. Roll the strip of magnesium ribbon into a coil and drop it into the acid. Now quickly place a beaker over the cylinder and invert. If you are careful, you will now have a cylinder full of acid standing upside-down in a beaker. Bubbles of a gas are given off by the magnesium ribbon and collect in the cylinder. When all the magnesium ribbon has disappeared, record the volume of gas produced. Subtract from this any air bubbles that leaked in at the beginning. Report your findings to the teacher. When all results are known, you should record them all in a table and then plot them on a graph. You should get a straight line.

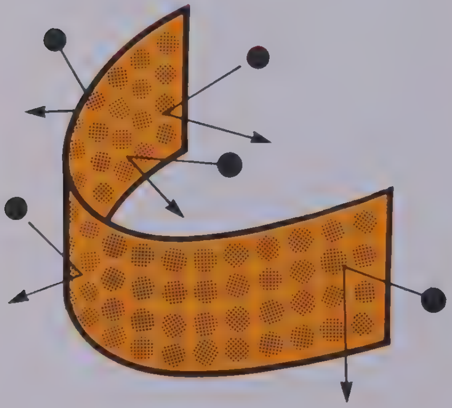


Various chemical tests show that the gas produced here is hydrogen.

QUESTIONS:

1. Should the graph go through point 0,0? Why?
2. Does each centimetre of magnesium ribbon produce the same amount of gas? What shape of graph should this produce?
3. What is the average volume of gas produced per centimetre of ribbon?

According to the particle theory, the acid solution contains certain molecules, the magnesium ribbon different ones. Dilute hydrochloric acid molecules collide with magnesium atoms on the ribbon, and as a result of this interaction, gas molecules are produced.



11.5 Rate of Reaction

In the first investigation in this chapter, you mixed different solutions together to form some rather interesting new substances. How long did the reactions take? Was there a time lag between the mixing and the formation of new compounds? Is this a rapid rate of reaction?

The second investigation showed you a slow rate of reaction. The magnesium strip reacted very slowly with the acid to form hydrogen gas. Why are some reactions fast and others slow? Can the rate of reaction be changed or controlled? What are the different factors which affect the rate of reaction? What do you think would happen if you heated the acid before you dropped in the magnesium strip?

Our atomic theory says that chemical reactions occur when molecules collide with enough force to alter the molecules. Atoms may switch from one molecule to another, or from one part of a molecule to another, or molecules may combine or even split up. In any case, each new molecule means a new substance will appear. If the particles collide more often, the new substances will be produced more quickly.

11.6 Investigation: Reaction Rate / Temperature

PROBLEM: HOW IS THE RATE OF REACTION AFFECTED BY TEMPERATURE?

MATERIALS:

Alka-Seltzer tablets
250 ml beaker
Bunsen burner

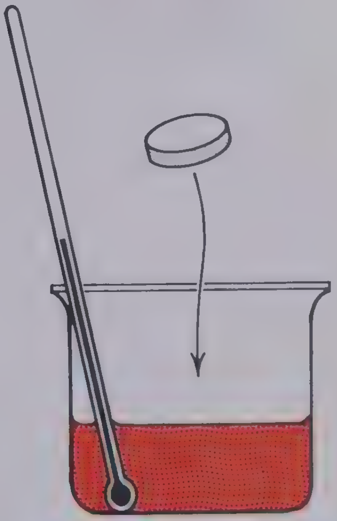
PROCEDURE:

Pour 100 ml of water into a 250 ml beaker. Your teacher will tell you what temperature to use. If you are working on your own, select several temperatures between 0°C and 100°C. Heat the water with your burner if necessary. Drop in an Alka-Seltzer tablet and time the reaction until all visible pieces of the tablet have reacted.

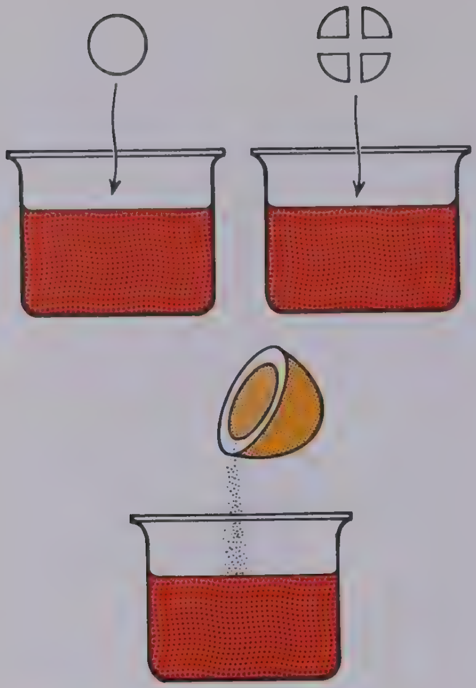
Repeat using other water temperatures. Collect the results of other groups in the class and record all this information on a large chart. Use this information to draw a graph of temperature and time.

QUESTIONS:

1. What observations did you make which suggest that Alka-Seltzer in water is a chemical reaction, not just dissolving?
2. Does extra heat increase the rate of reaction or slow it down?
3. According to our particle theory, what effect does heat have on the molecules of the water and Alka-Seltzer?
4. When molecules collide, a chemical reaction can take place. The rate of reaction will increase if the number of collisions increases. Can heat increase the number of collisions per second? Explain.
5. What other factors should increase the number of collisions and the rate of reaction?

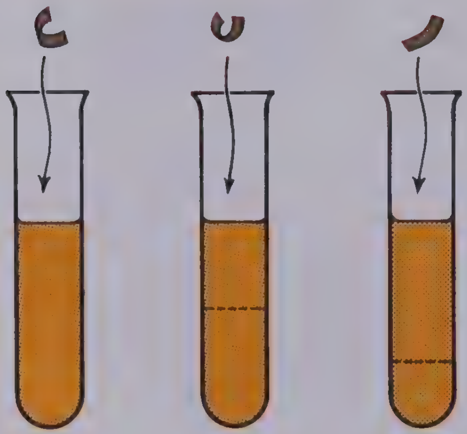


Don't wait until the last bubble disappears – stop timing when the last bits of a tablet disappear. Some of the tablet will not react, and will fall to the bottom of the beaker.



Rate of reaction plays a part in physical reactions as well. The rate at which a sugar cube will dissolve in water depends on the temperature of the water, and the surface area of the cube. Crushing the cube drastically changes the dissolving time. Can you see that the same explanation works for both chemical and physical reactions?

What do you think would happen if you did the hydrochloric acid and magnesium ribbon experiment in a closed container? Could you control its rate of reaction as well?



11.7 Investigation: Rate / Surface Area

PROBLEM: WHAT IS THE EFFECT OF SURFACE AREA ON RATE OF REACTION?

MATERIALS:

3 Alka-Seltzer tablets
mortar and pestle
3-250 ml beakers

PROCEDURE:

Time three Alka-Seltzers as they react in 100 ml of room-temperature water. Leave one whole, break the second into quarters and grind the third to a powder with a mortar and pestle.

QUESTIONS:

1. How can increasing the surface area increase the number of molecules colliding each second?
2. What should happen if the beaker of water is stirred as the powder is added? Explain.

11.8 Investigation: Reaction Rate / Concentration

PROBLEM: DOES THE RATE OF REACTION DEPEND ON THE CONCENTRATION OF REACTANTS?

MATERIALS:

dilute hydrochloric acid
magnesium ribbon
3 test tubes

PROCEDURE:

Pour dilute hydrochloric acid into three small test tubes. Put 10 ml in the first, 5 ml in the next and 2.5 ml in the last. Now add water to the last two test tubes to make them each 10 ml.

Cut three strips of magnesium ribbon, each 1 cm long. Drop one of them in each of the test tubes. Measure the time it takes for the magnesium to react in each case.

QUESTIONS:

1. Explain why a reduced concentration reduces the number of collisions between molecules of the reacting substances, and, as well, the rate of reaction.
2. What do you think would happen if you dropped another 1 cm long strip of magnesium into each test tube? Would it take the same time as before? Explain.

11.9 Investigation: Rate / Pressure

PROBLEM: WHAT IS THE EFFECT OF PRESSURE ON RATE OF REACTION?

MATERIALS:

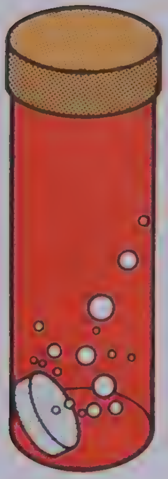
empty Alka-Seltzer bottle
transparent tape
Alka-Seltzer tablet

PROCEDURE:

Put several layers of transparent tape around an empty Alka-Seltzer bottle (in case it explodes) to protect yourself. Fill it with water, drop in an Alka-Seltzer and screw the top on tightly. You will notice that you can control the rate of reaction by unscrewing the cap slightly to release some of the pressure. Loosen and tighten it several times and watch what happens.

QUESTIONS:

1. Try to explain what you have observed, using our particle theory. What should happen if the gas cannot escape but must remain in the solution?
2. What would happen if you dissolved a tablet in a beaker of water on the surface of the Moon?



11.10 Rate of Reaction: Summary

The main factors we have seen which influence rate of reaction are:

1. temperature
2. concentration
3. surface area
4. pressure

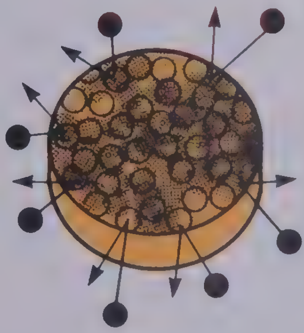
Our particle theory explains how each of these factors works. In many chemical reactions, new molecules are formed by the collision of molecules of the reactants. The original molecules are broken into parts which combine in different ways to form new molecules. The rate of reaction depends on the number of molecular collisions. A greater number of collisions per second produces more new molecules per second, and an increased rate of reaction.

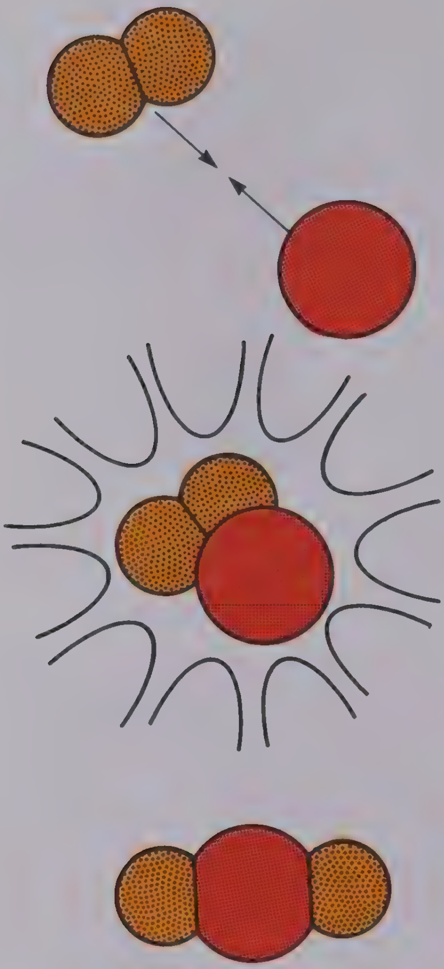
Our theory tells us that a hot object has fast-moving molecules. A collection of fast-moving particles should collide more often, increasing the rate of reaction.

A greater concentration should increase the rate of reaction. If more reacting particles are present, there will be a greater chance for a collision between the correct kinds of particles, and the reaction should go faster.

When one of the reactants is a solid, surface area becomes important. Only molecules on its outside surface can be hit by the other reactant. By breaking the solid down into smaller pieces, or by grinding it to a powder, many more molecules are exposed, more collisions take place and the reaction rate increases.

At the center of the sun the pressure is almost unimaginable. Here the collisions are so tremendous that nuclear reactions occur. Atoms are shoved together to form new atoms, not just new molecules. The principle substance found in stars is hydrogen. In the core of the star, this is used first to manufacture helium, then heavier atoms like carbon, or iron, and perhaps eventually uranium atoms. Present theories of astrophysics maintain that all the heavier atoms were made inside stars, which have long since exploded, sending debris in all directions to build up new stars, planets and rocks.





The molecules of oxygen in the atmosphere each consist of two oxygen atoms joined together. A molecule with three oxygen atoms joined is a particle of "ozone". There is a layer of ozone in the upper atmosphere which helps to protect us from the sun's ultra-violet rays.

A jet engine is similar to a rocket engine, but the jet engine takes in air from the atmosphere to get oxygen for the fuel.

11.11 Oxidation

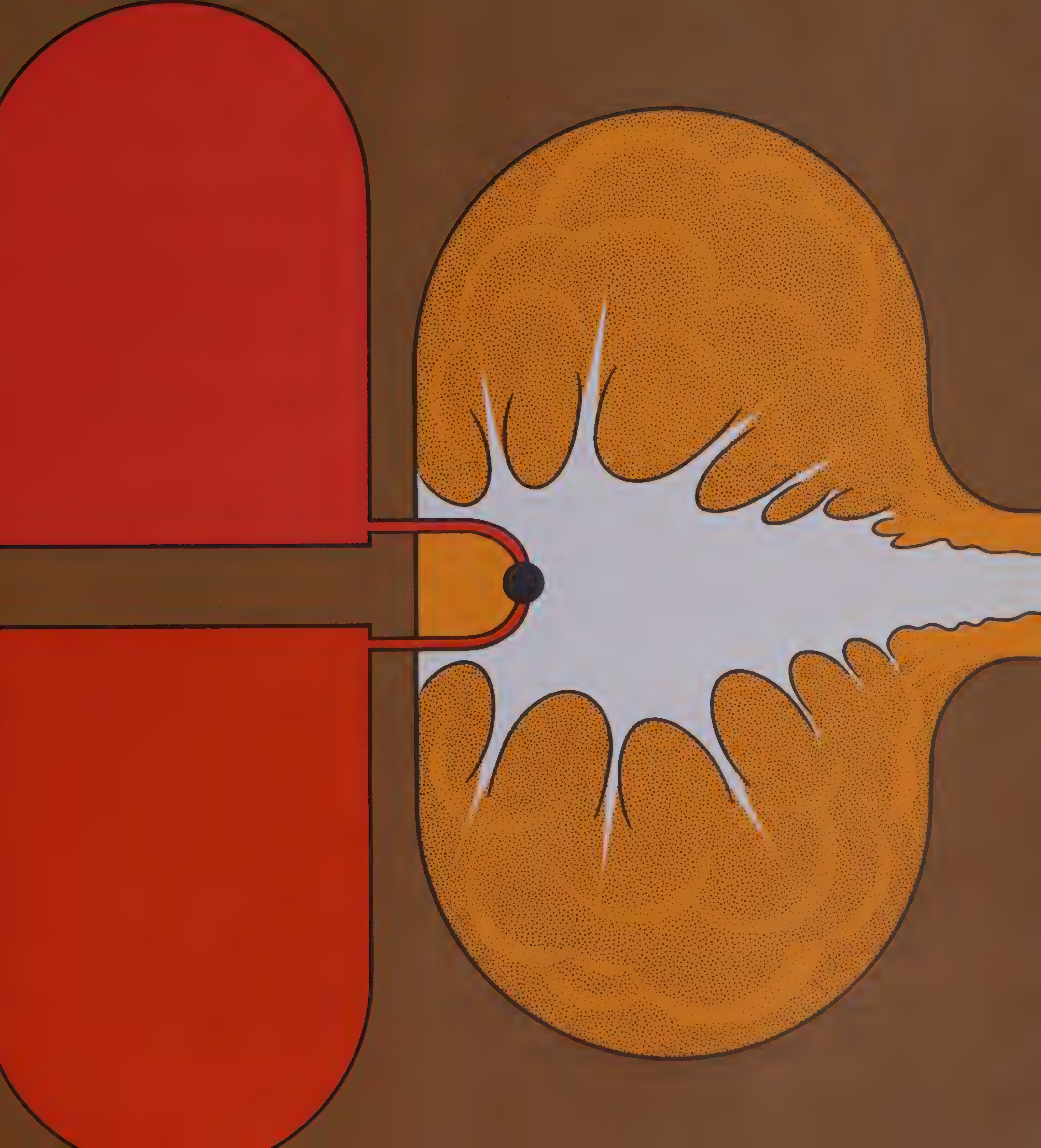
When molecules of a substance combine with molecules of oxygen, the reaction is called "oxidation". The family of oxygen reactions is interesting because it contains many examples of the kinds of reactions we have been talking about, and because many of them are quite important in everyday life, at home, in industry and even on the Moon.

Charcoal, as used in a barbecue, is mostly carbon. If you heat it enough, using some kind of barbecue starter, these carbon atoms vibrate faster and faster. The air around the charcoal contains oxygen atoms. At normal temperatures, these molecules collide with the charcoal and bounce back, unchanged. At high temperatures, the force of the collision causes carbon atoms and oxygen atoms to stick together, producing even more heat. Soon the reaction proceeds by itself. Heat from the combining of carbon and oxygen atoms heats other carbon and oxygen atoms, producing more high-speed collisions. The oxidation, or combustion, continues until all the carbon atoms have combined. The heat produced is easily hot enough to cook hamburgers or steaks, and has been used in the past by blacksmiths to heat iron to white heat, hot enough to form into useful objects with a hammer or by bending.

Even faster oxidation occurs in rocket engines. In deep space there is no oxygen. It must be carried by the rocket, as a liquid, to save space. The fuel can be gasoline, kerosene or liquid hydrogen or any of dozens of other materials. Pumps send fuel and oxygen into the engine where they are ignited in a kind of continuous, controlled explosion. The exhaust gases shoot out in one direction, forcing the rocket to move in the other.

Pressure also changes the rate of reaction by changing the number of collisions per second. When one of the products of a reaction is a gas, increasing the pressure keeps the gas molecules from escaping. The remaining reactant molecules find themselves hitting these gas molecules instead of other reactant molecules. This slows the reaction. You should be able to figure out what will happen when one of the reactants is a gas, and the pressure is increased. Sometimes, gases are found to be both reactants and product. Predicting what will happen in these situations is too difficult for us, but involves the same principles.

Oxidation occurs at normal temperatures with most metals, but only very slowly. Even at room temperature, some oxygen molecules are moving fast enough for oxidation to take place. When iron is oxidized, the product is called rust. Rust is a new compound formed from iron and oxygen atoms. Aluminum oxidizes almost immediately when exposed to the air. A thin film



of oxide forms, which coats the aluminum and prevents any more oxidation. Silver tarnishes when exposed to the air. Here the oxide is black.

Some metals, such as gold and platinum, do not oxidize easily, if at all, at normal temperatures, and retain their luster for long periods of time.

Oxidation is the reaction which produces the energy needed for life. In all plants and animals, stored food, sugar, starch or fats are oxidized to produce heat for warmth and the energy for movement.

Inside the cylinder of a car engine the mixture of vaporized fuel and air is compressed and then ignited by a spark from the spark plug. The high pressure produces a high rate of reaction and the explosion which drives the piston downwards.

In man, this process takes place inside individual cells. Each one must be supplied with all the necessary ingredients before oxidation can take place.

We could continue, but we would soon be into the material covered by more advanced courses in biology, chemistry and physics.

11.12 Summary

1. A physical change, such as a change from gas to liquid or solid, is one in which the kind of matter is unchanged: the particles remain the same.

2. A chemical change, such as burning, is one in which new kinds of matter are produced: the particles are changed.

The rate of reaction of oxidation inside your body is obviously slower than oxidation in a fireplace, but faster than oxidation on rusting metal. The rate of reaction inside your body is rigidly controlled to produce just the right amount of heat energy. The human body can withstand only a few degrees variation before we say we are "sick".

3. In a chemical change, the amount of product depends directly on the amount of raw material used in the reaction.

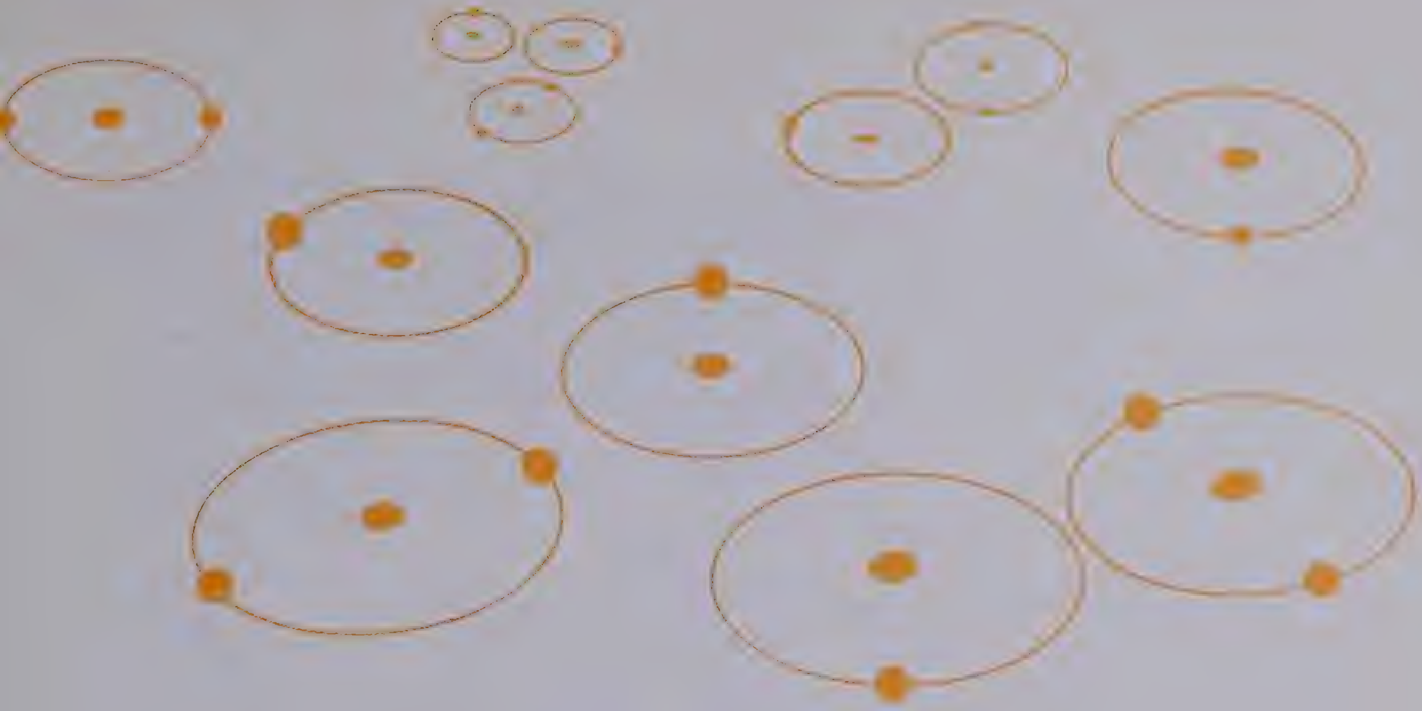
4. In a chemical reaction, the rate of reaction is increased by an increase in temperature, by an increase in the surface area of the reactants, by an increase in the concentration of the reactants or, sometimes, when a gas is produced, by a decrease in the atmospheric pressure around the reaction.

5. Burning and rusting, oxidation and the energy-producing reactions inside cells in plants and animals are chemical reactions in which oxygen combines with a substance to form new substances and release energy.

Hydrogen atoms make up 93% of the atoms in the universe. Helium gas accounts for the remaining 7%. Oxygen is about 0.05% and the remaining elements about 0.04%.

11.13 Further Investigations

Most matter is normally neutral. It will not exert an electric force on another piece of matter. Matter is neutral when each atom or molecule has an equal number of positive and negative charges, but this does not happen very often. Usually one kind of atom gives some of its charge to another kind of atom, sometimes permanently, sometimes for a short time. Some



atoms or molecules will then be negative and others positive. The force of attraction between the positive and negative particles holds the material together. Only the total number of each charge is the same.

Some materials, such as hydrogen, like to give up negative charges. If they do this, they then become positive. Others like to take on negative charges, such as oxygen. Obviously they then become negative. When two materials such as these are mixed together, then it is likely that they will collide and exchange charges. Once this happens, the forces of attraction take over and molecules form. When two hydrogens connect with an oxygen atom, water is formed. When two hydrogens connect up with two oxygens, a molecule of hydrogen peroxide is formed, a compound with quite different properties from water.

The negative charges in atoms are carried by tiny particles called electrons. An atom could lose all its electrons and still have the same mass. The mass of an atom is concentrated at its center, or nucleus. There are found the particles that carry positive charge, the protons. The charge on a proton just balances the charge on an electron. A neutral atom has an equal number of electrons and protons.

In a chemical reaction, atoms gain or lose electrons. Gaining one or more electrons makes an atom negative. Losing one or more electrons makes an atom positive. Such atoms, whether they have gained or lost electrons, are called ions. There are positive ions and negative ions.

On the Earth, the distribution of elements is different. Here there is about 47% oxygen, 19% magnesium, 17% iron, 12% silicon and 5% for all the rest. (What happened to hydrogen and helium?) As before, we are going by the number of atoms, not by mass.

In 1970, a scanning electron microscope, built by Albert V. Crewe of the University of Chicago, produced a "photograph" of a pair of uranium atoms - two small, round blurs

Atoms can be classified in many ways – in order of increasing density, for instance, or as metals or non-metals, as solids, liquids or gases or in hundreds of other ways. Chemists classify atoms in several ways at the same time. First, they put them in order of increasing positive charge. An atom can have one, two, three, four, five, six and so on – up to 103 positively charged protons in its nucleus. Each one is a different element. The number of protons is called the Atomic Number. Here are the first nineteen elements.

Atomic Number	Element	State	Density (kg/m^3)	Probable Charge on ion	Melting Point (°C)
1	hydrogen	gas	0.09	+1	–259
2	helium	gas	0.18	0	–273
3	lithium	solid	530	+1	179
4	beryllium	solid	1850	+2	1278
5	boron	solid	2340	+3	2300
6	carbon	solid	3000	+2, +3, +4	3550
7	nitrogen	gas	1.3	+2,–3, +5	–210
8	oxygen	gas	1.4	–2	–218
9	fluorine	gas	1.7	–1	–220
10	neon	gas	0.9	0	–249
11	sodium	solid	970	+1	98
12	magnesium	solid	1740	+2	651
13	aluminum	solid	2700	+3	660
14	silicon	solid	2330	+4	1410
15	phosphorus	solid	2000	–3, +5	44
16	sulphur	solid	2000	–2, +4, +6	113
17	chlorine	gas	3.2	–1	–101
18	argon	gas	1.8	0	–189
19	potassium	solid	860	+1	64

Can you see several patterns forming? What we would like to try to do is to predict the properties of element 20. Will it be a solid, a liquid or a gas? Roughly, what will its density and melting points be? Can you predict the kind of ions it sometimes forms? The answer is on page 237.

As you can see, the properties of the elements repeat themselves as you move up the scale of atomic numbers. Around 1900, this repetition was noticed by Dimitri Mendeleev, who then was able to arrange all the known elements in a "periodic table", without knowing, for sure, any of the atomic numbers. Sometimes he was forced to leave spaces in his table because the properties did not match. In every case a new element with the required properties was discovered later.

11.14 Review

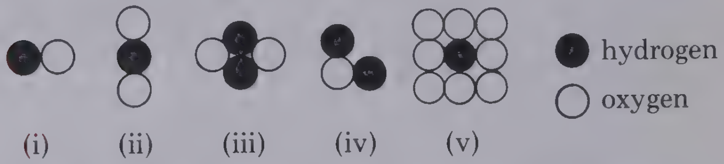
1. Classify each of the following as either a physical or chemical change. If a physical change occurs, state what kind of physical change.
    (a) toasting bread
    (b) eating ice cream
    (c) making a chocolate milkshake
    (d) using a flashlight
    (e) making ice cubes
    (f) making coffee
    (g) burning leaves
    (h) firing a cannon
    (i) growing a petunia
    (j) drying clothes
2. Give an example from everyday life of each of the following physical changes.
    (a) dissolving
    (b) melting
    (c) solidification
    (d) crystallization
    (e) boiling
    (f) evaporation
3. Heat energy is involved in physical changes. State whether heat is released or absorbed in each of the processes in question 2.
4. Heat energy is also involved in chemical changes: State whether heat is released (an exothermic reaction) or absorbed (an endothermic reaction) in each of the following cases:
    (a) Alka seltzer in water
    (b) a burning match
    (c) starting a fire in the fireplace
    (d) making toast
5. List four ways of increasing the rate of a chemical reaction.
6. List four ways of decreasing the rate of a chemical reaction.
7. When hydrogen gas and oxygen gas are mixed, and ignited, a violent explosion can occur, and water vapor is produced. Usually there is some of one of the gases left over, though all of one of the gases has been used. Let us examine this reaction more closely.
    (a) The following table gives the results of several experiments. Analyze the first few sets of results, then see if you can finish the rest of the table.

mass of oxygen gas (g)	mass of hydrogen gas (g)	mass of water vapor produced (g)	mass of gas remaining (g)	kind of gas remaining
8	2	9	1	hydrogen
8	3	9	2	hydrogen
10	1	9	2	oxygen
12	1	9	4	oxygen
8	1			
16	2			
18	2			
24	3			
32	7			

This is the kind of data that John Dalton might have used when he finally decided that there must be atoms, which combine with one another in certain ways to produce new substances.

Science may be subdivided into biology and physical science. Biology involves the study of living things: plants and animals, their structure and their function. Physical science, the subject of this text, is concerned with non-living materials. It is further sub-divided into physics and chemistry. Chemistry deals with the reactions between atoms and molecules. Chemists study how to make new substances from known ones, and how to improve these substances and produce them more rapidly. Physicists search for elementary particles, calculate orbits for space vehicles, construct lasers for communication, energy conservation devices (like solar cells), integrated circuits for computers, calculators, watches and so on. In addition, there are biochemists, biophysicists and physical chemists, not to mention geologists and geophysicists. Perhaps you will discover a part of science that interests you enough to make it your career.

(b) What must be true about the total mass before the reaction and the total mass after the reaction?
(c) What is the ratio of oxygen to hydrogen in water, by mass?
(d) Since water is made of molecules, and all the molecules are supposed to be identical, what is the ratio of oxygen to hydrogen in water molecules, by mass?
(e)



Here are some possible water molecules, built from oxygen and hydrogen atoms. As you have just learned, a water molecule contains eight times as much oxygen as hydrogen, by mass. Let us call the mass of one hydrogen atom one glop. What must the mass of one oxygen atom be, according to each of the possible molecules?
(f) Which of the above models is actually the arrangement of atoms in a water molecule?
(g) The mass of a hydrogen atom is 1.67×10^{-24} g. What is the mass of an oxygen atom?
(h) What is the mass of a water molecule?
(i) How many water molecules are there in 1 g of water?

11.15 Instructional Objectives

1. To distinguish between a chemical and a physical reaction.
2. To identify, classify and distinguish processes as physical or chemical reactions, changes of state, dissolving, crystallization, burning, rusting, electrolysis and so on.
3. To identify and explain how the four factors mentioned affect the rate of a chemical reaction, using the particle motion theory.
4. To use the particle theory to explain why the mass of the product of a chemical reaction is directly dependent on the amount of reactant used.
5. To explain the various forms of oxidation described, using the particle motion theory.

11.16 Glossary

atomic theory
chemical change
chemical reaction
combustion
oxidation
pressure
reactant

Appendix

The Metric System

By international agreement, units and symbols have been defined for each of the following quantities.

quantity	unit	symbol
length	metre	m
mass	kilogram	kg
time	second	s
temperature	degree Celsius	°C

Other units are defined as needed in terms of these basic quantities.

quantity	unit	symbol
area	square metre	m^2
volume	cubic metre	m^3
volume	litre	ℓ
heat	joule	J
work	joule	J
energy	joule	J
speed	metre per second	m/s
force	newton	N
specific heat capacity	joules per kilogram degree Celsius	J/(kg · °C)
specific latent heat	joules per kilogram	J/kg

Larger or smaller units are formed from the base units using the following prefixes.

prefix	symbol	multiple
giga	G	1 000 000 000
mega	M	1 000 000
kilo	k	1 000
centi	c	1/100
milli	m	1/1000
micro	μ	1/1 000 000
nano	n	1/1 000 000 000

Examples: 1 km = 1000 m
$1\ \mu g = 1/1\ 000\ 000$ g
$1\ ml = 1/1000\ \ell$

Useful Relationships

1. Length

1 kilometre	= 1000 metres	1 km	= 1000 m
1 metre	= 100 centimetres	1 m	= 100 cm
	= 1000 millimetres		= 1000 mm
1 centimetre	= 10 millimetres	1 cm	= 10 mm

2. Area

1 square metre = 10 000 square centimetres
$1\ m^2 = 10\ 000\ cm^2$

1 square centimetre = 100 square millimetres
$1\ cm^2 = 100\ mm^2$

3. Volume

1 cubic metre = 1000 litres
= 1 000 000 cubic centimetres
= 1 000 000 millilitres
= 1 000 000 000 cubic millimetres

$1\ m^3 = 1000\ \ell$
$= 1\ 000\ 000\ cm^3$
$= 1\ 000\ 000$ ml
$= 1\ 000\ 000\ 000\ mm^3$

1 litre	= 1000 millilitres	$1\ \ell$	= 1000 ml
	= 1000 cubic centimetres		$= 1000\ cm^3$

4. Mass

1 kilogram	= 1000 grams	1 kg	= 1000 g
	= 1 000 000 milligrams		= 1 000 000 mg
1 gram	= 1000 milligrams	1 g	= 1000 mg
1 tonne	= 1000 kilograms	1 t	= 1000 kg

5. Density

1 gram per millilitre = 1000 kilograms per cubic metre

1 kilogram per cubic metre = 1 gram per litre
= 1 milligram per millilitre

$1\ kg/m^3 = 1\ g/\ell$
= 1 mg/ml

$1\ g/ml = 1000\ kg/m^3$

Glossary

absolute zero The hypothetical temperature (–273.18°C) at which a substance would have no molecular motion or heat.
amorphous sulphur A form of sulphur produced by intense heating and characterized by its lack of crystalline structure.
antifreeze A substance with a low freezing point, used to prevent freezing in water-cooled automobile engines.
approximation A result that is not exact but approaches the limits required.
Aristotle Greek philosopher of the fourth century BC. He suggested that there are four basic types of matter – earth, air, fire and water – and that these four combine to produce all other kinds of matter.
assumption A fact taken for granted.
atmospheric (air) pressure The force of the atmosphere pushing down on each square metre of the Earth's surface.
atom The smallest single complete unit of an element.
atomic force The force between atoms which holds them together.
atomic theory All forms of matter (solids, liquids, gases) are composed of atoms.
attract To draw to or toward.
axis One of the two straight lines which form the boundaries of a graph.

Bacon, Sir Francis English writer who proposed that heat is the motion of the particles of which all matter is composed.
block The roller part of a pulley, in a block and tackle.
block and tackle A machine consisting of pulleys and ropes, used for moving objects and for doing work.
boil To change from the liquid to the gaseous state by the addition of heat, at a given temperature.
Brownian motion Random motion of smoke particles, occurring as a result of collisions with moving air particles. Named after nineteenth-century Scottish botanist Robert Brown, who first noticed the effect.
buoyancy The force which partially or completely counteracts gravity when an object is immersed in a liquid.

calculate To make a computation; to arrive at a conclusion after taking into account all the surrounding circumstances.
caloric fluid theory Theory which proposed that heat is a substance which can flow into or out of objects.
capillary action A force between the molecules at the surface of a liquid which causes it to rise in a capillary tube.
Celsius, Anders Swedish astronomer who proposed a temperature scale based on one hundred degrees between the freezing point of water and the boiling point of water.
Celsius scale Temperature scale which uses the melting point of ice as 0°C and the boiling point of water as 100°C.
centimetre (cm) A unit of length equal to 1/100 part of a metre.
change of state Variation from one of the forms of matter (solid, liquid or gas) to another.
chemical change A change, usually the result of some kind of reaction, in which new molecules are created.
chemical potential energy Energy stored in matter.
chemical reaction A reaction in which a chemical change takes place: i.e., molecules are changed from one type to another.
cleavage The property of crystals to break along certain lines.
combustion Burning.
compound Matter made by combining the atoms of pure elements to create molecules such as sodium chloride.
conclusion The results of experiments: i.e., the statement of whether or not the hypothesis was correct.
condensation To reduce to a more dense form, as a vapor is reduced to a liquid.
constant Not changing, remaining the same.
continuous theory of matter Theory which proposed that matter is continuous, that a piece of matter fills completely the space it occupies.
Crookes' radiometer Instrument used to detect radiant energy and to measure its intensity.
crystal Solid form of a substance whose molecules are arranged in a definite repeating pattern, so that the exterior surface of the mass is made of plane faces in a symmetrical arrangement.
crystallize To make into crystals.

data Facts or figures drawn from an experiment, from which conclusions can be made.
Davey, Humphrey Eighteenth-century English scientist who provided additional experimental evidence for the particle motion theory.
Democritus Greek who formulated a theory of matter which proposed that matter is composed of tiny particles called atoms.
density The ratio of mass to volume.
deposit Coating of matter left after boiling, evaporation, filtration, etc.
diffusion The spreading of molecules in different directions. Occurs especially when the molecules of two or more substances are mixed.

dissolve To break down into smaller particles and intermingle with the particles of another substance (usually a liquid).

efficiency The ratio of useful work done to the total work done by a machine.

electric force The force of attraction or repulsion exerted by electrically charged bodies.

electrode Either of two terminals of an electric source. The positive is called an anode; the negative is called a cathode.

electrolysis The decomposition of a compound, especially water, into ions by the action of an electric current passing through it.

element Any pure substance consisting of one type of particle only.

energy Capacity for doing work.

evaporate To change from a liquid state into a vapor.

evidence Signs or indications that tend to prove a theory.

exert To exercise force, pressure.

experiment A test or a trial of an hypothesis or a problem.

extrapolate To read points from a graph, beyond the range of points already plotted.

first-class lever A simple machine used to lift. It is composed of a bar supported on a point (fulcrum). The fulcrum is placed between the load and lifting force.

float Due to buoyant force, to remain suspended at or near the surface of a liquid.

flotation Buoyancy.

force A push or pull exerted on an object.

formulate To express in a definite or systematic way the idea behind a hypothesis.

freeze To change from the liquid state into the solid state.

friction The force, opposing motion, which is created when one object rubs against another.

fulcrum The point at which a lever bar is balanced and around which it rotates.

fusion Melting.

Galileo Italian astronomer and physicist who proposed that increased particle motion causes increased heat.

gas State of matter. The fluid form of a substance which can expand indefinitely and completely fill its container.

gram(g) Unit of mass,1/1000 part of a kilogram.

graph A diagram showing the relationship between a change in one quantity and a change in another, which depends on the first.

gravitational potential energy Energy of position: e.g., a ball poised on the crest of a hill possesses gravitational potential energy.

gravity Force that tends to pull all masses toward the center of the Earth.

heat The form of energy consisting of the motion of the molecules of matter.

heat exchange The temperature of the mixture that results when a hot liquid and a cold liquid are combined is the result of a heat exchange between the two.

heat transfer When energy in the form of heat moves from one substance to another: e.g., a teaspoon in a cup of hot tea increases in temperature due to the transfer of heat from the tea.

horizontal Perpendicular to vertical; parallel to the horizon.

hydrometer Instrument used to determine the density of liquids.

hypothesis The proposed answer to a problem, to be proved or disproved by experimentation.

inclined plane A flat surface forming an angle with the horizontal surface. A simple machine used for raising or lowering loads.

interpolate To read a point on a graph, between known points.

Joule, James Prescott English physicist who described quantities of heat. The joule (J) is the basic unit of work and energy in the metric system.

Lord Kelvin English physicist and mathematician. The Kelvin temperature scale begins at –273.18° C, with degrees the same size as Celsius degrees.

kilogram (kg) Unit of mass, equal to 1000 g.

kilojoule (kJ) One kilojoule equals 1000 J. Used to indicate the energy content of foods.

kinetic energy The energy of an object which results from its motion.

Leucippus An early Greek philosopher who, like Democritus, proposed that all matter is made up of particles.

lever A simple machine composed of a bar turning on a support, used for lifting.

liquid Fluid; capable of flowing; not solid or gaseous.

liquifaction Change of state from gas to liquid; same as condensation.

litre (ℓ) Basic unit of volume, defined as the space occupied by a cube 10 cm by 10 cm by 10 cm.

magnetic force The force with which a magnet attracts or repels a piece of iron or steel.

mass The quantity of matter in a body, measured in kilograms.

matter What all things are made of. Whatever occupies space and has mass is composed of matter.

Maxwell, James Clerk Proposed the particle motion theory, which states that all matter is composed of particles continually in motion. The speed of the particle motion is proportional to the temperature of the matter.

mechanical advantage The ratio of load force to effort force for any machine; a term expressing how much easier work is when a machine is used to do the work.

mechanical energy The total of the kinetic and potential energies of an object.

melt To change from a solid to a liquid.

meteorologist A scientist who studies weather and climate.

metre (m) Standard unit of length in the metric system.

millilitre (ml) 1/1000 of a litre.

mixture The result of a combination of ingredients.

molecule The smallest part of a compound that can exist and still retain the characteristics of that compound.

monoclinic sulphur One of the three forms of sulphur, characterized by its long, needle-like crystals.

newton (N) The basic unit of force.

newton metre (N·m) The amount of work done when a force of 1 N pushes an object 1 m, equivalent to 1 J.

nuclear reaction A chemical change involving the chain reactions of fissionable materials.

observation Notation and recording of facts and events in an experiment.

opaque Not letting light pass through.

paper chromatography The separation on porous paper into components of mixtures.

particle A small piece of matter, sometimes an atom or a molecule.

particle motion theory A theory of physics which proposes that all particles of all matter are constantly in motion, and that the amount of motion is proportional to the temperature of the matter.

particle theory of matter States that matter is particulate, made of billions of particles joined together.

pendulum A mass suspended from a fixed point so as to swing freely back and forth.

perpendicular At right angles.

phenomenon Observable or describable fact.

potential energy Energy stored in some form, such as gravitational, magnetic or chemical potential energy.

prediction Statement of likelihood of the occurrence of a future event.

pressure Force per unit area (N/m^2).

property Characteristic of a substance.

pulley Wheel grooved for cord, rope, etc. to pass over. A simple machine used to increase mechanical advantage.

pure substance Composed of only one type of atom or molecule.

radioactive Capable of giving off energy in the form of rays (alpha, gamma and beta rays).

reactant Any of the substances participating in a chemical reaction.

regelation Re-freezing. To make into a gel again.

repel To reject or force back.

rhombic crystals Arrangements of crystals in a diamond shape.

saturated solution A solution containing so much dissolved substance that no more can be dissolved while the solution remains at the same temperature.

scientific method A method of problem solving characterized by the following: a question, a possible answer (hypothesis), tests (experiments) to see if the answer is correct and a statement (conclusion) of the possible answer to the question.

second-class lever A simple machine made up of a bar and a point (fulcrum) around which the bar rotates. The fulcrum is at one end, the lifting force at the other end and the load in between.

solar energy Energy from the sun, in the form of heat and light.

solid State of matter characterized by constant mass, volume and shape.

solidification Change of state of matter from liquid to solid.

solidify To make solid.

solute Substance dissolved in another: e.g., sugar in coffee.

solution A special kind of mixture in which each of the substances may lose or change its basic properties.

solvent The matter in which the solute is dissolved: e.g., sugar in coffee – coffee is the solvent.

specific heat capacity(*c*) The amount of heat required to change the temperature of a specified amount of a material (1 kg) by a specified number of degrees (1 °C) in J/ (kg · °C).

steam Vapor produced by boiling water after mist condenses.

structure The manner in which the elements of anything are organized.

sublimation Change in state from a gas to a solid or from a solid to a gas.

substance Matter: an element, a compound or a mixture.
supercool To cool below freezing without causing solidification or crystallization.
supersaturated solution A solution containing more solute than would normally be possible at a given temperature. The addition of heat allows the increased amount of solute to dissolve in the solution.
suspension A mixture in which particles of a substance are mixed with a fluid but are undissolved.

tackle Rope, of a block and tackle.
temperature Measurement of heat intensity or amount of particle motion in a substance, in degrees Celsius.
Thales of Miletus Greek wise man (624-546 BC) who said that all matter is really water in different forms: i.e., solid, liquid or gas.
theories of matter Proposed ideas about the nature of matter. The particle theory of matter and the continuous theory of matter are the two main ones.
theory An idea proposed as an answer to a problem.
thermodynamics Science concerned with the relationship between heat and work.
Thompson, Sir Benjamin English physicist who studied the nature of heat and contributed further evidence to justify the theory of particle motion.
translucent Allowing light to pass through but scattering the light so that objects do not clearly show through.
transmit Conduct.
transparent Allowing light to pass through, with little or no distortion.

unsaturated solution One in which more of the solute could be dissolved, without the addition of heat.

vertical Perpendicular to horizontal; at right angles to the horizon.
volume The amount of space occupied by an object.

weight The force which gravity exerts on an object, pulling it toward the center of the Earth.
work The transfer of energy from one object to another as a result of a force acting on the object, causing it to move in the direction the force is moving.

ANSWER
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